

ELECTRONIC FUNDAMENTALS

SERVICE PRACTICES 32

CATHODE RAY OSCILLOSCOPE I

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Service Practices 32

INTRODUCTION

One of the most useful measuring instruments a radio and television serviceman can own is an oscilloscope. This instrument (Fig. 32-1) can measure the peak-to-peak value of a sinusoidal voltage (Fig. 32-2), and it can measure nonsinusoidal waves (Fig. 32-3). Furthermore, the oscilloscope can measure the instantaneous amplitude, frequency, waveform shape, and other characteristics of a-c voltage over a wide range of frequencies. Therefore the oscilloscope is a useful supplement to the handy portable a-c voltmeter, which gives root-mean-square measurements of sinusoidal voltages. Among the tests for which an oscilloscope is useful are distortion and hum tests of audio amplifiers and audio-frequency response checks.

The theory of operation of an oscilloscope is covered in this booklet. A later booklet covers the use of an oscilloscope in servic-

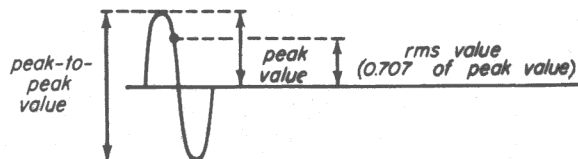


Fig. 32-2

ing radio receivers. As you progress to your study of television receivers, you will learn how to use the oscilloscope to service television sets.

At certain points, you will see references to the controls on the RCA Cathode-Ray Oscilloscope Type WO-78A, which is illustrated in the Appendix to this lesson. If you are able to associate what you read about the circuits of oscilloscopes with the names of the controls, you will be better prepared to use oscilloscopes in your service work.

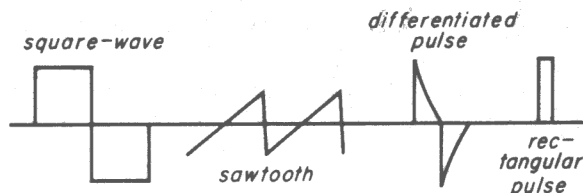


Fig. 32-3

32-1. THE CATHODE-RAY TUBE

A major portion of the oscilloscope is the *cathode-ray tube* (see Fig. 32-4). A cathode-ray tube is a special kind of electron tube. It is much larger than the radio receiving tubes. The front of this tube forms a viewing screen on which electrical signals are reproduced. In order to understand how an oscilloscope operates, we must know something about the construction and operation of a cathode-ray tube.

Cathode Ray. Streams of electrons moving at very high velocity (approximately 10,000 miles per second or higher) are called *cathode rays*. Rays of this type are generated when.

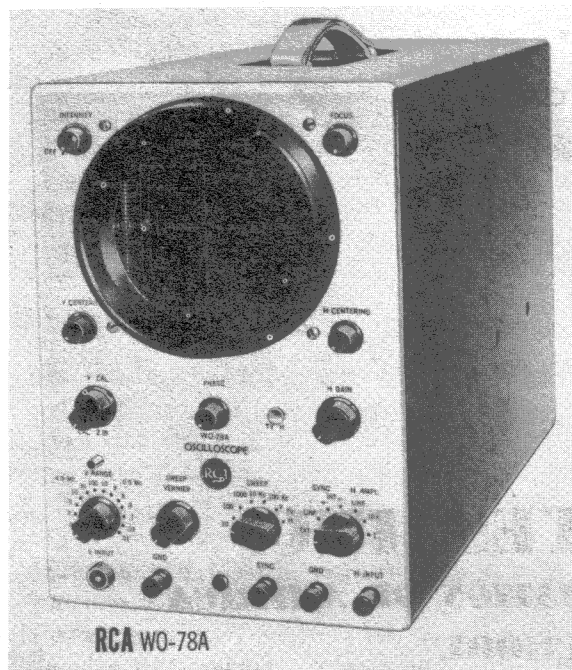


Fig. 32-1

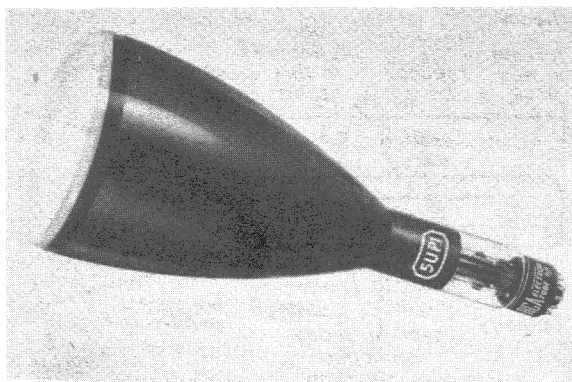


Fig. 32-4

the cathode electrode in a tube emits electrons towards a plate whose potential with respect to cathode is extremely high (see Fig. 32-5). The tube must be a long one, to permit the electrons to be accelerated to a high velocity (just as an airplane runway must be long, to permit planes to pick up enough speed for their take-off).

A Rudimentary Cathode-ray Tube. Cathode rays must first be created, properly shaped, then caused to move over the viewing screen in accordance with the variations of the electrical signal to be measured. Let's consider the way in which cathode rays are formed in an elementary C-R tube. (C-R tube and CRT are both abbreviated terms for cathode-ray tube.) Figure 32-6a is a simplified drawing that illustrates the way in which the cathode-ray tube works. Basically, what happens in this tube is that a stream of electrons from the cathode is made to strike the screen of the tube. The screen, which is made of glass and coated with a fluorescent material, lights up when the electrons strike it.

First let's examine the cathode of this tube (Fig. 32-6b). The filament, which gets its power from a filament transformer or a filament winding on the power transform-

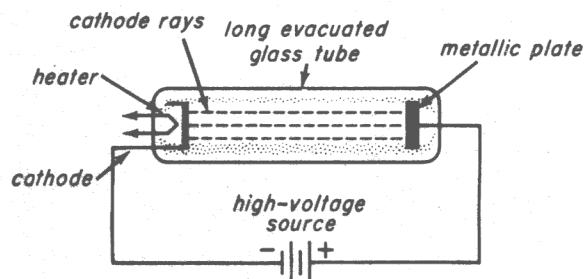


Fig. 32-5

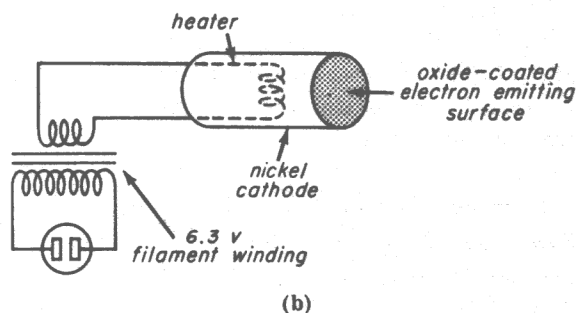
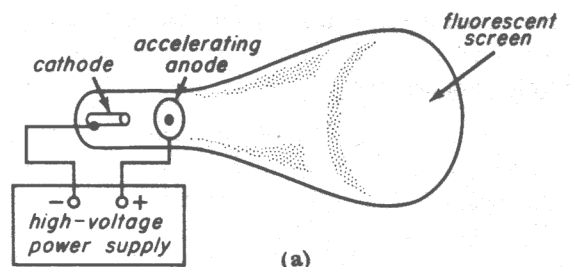


Fig. 32-6

er, heats the cathode, which has an oxide-coated surface that emits electrons when it is heated. This cathode emits electrons from its front surface only. Therefore electrons are emitted only in the direction of the screen. The electrons emitted from the cathode do not have enough velocity to reach the screen. An accelerating electrode or anode speeds them up, (just as screen grids accelerate electrons in receiving tubes). Since the distance between cathodes and viewing screen is relatively great, a very high acceleration voltage is needed. Note, in Fig. 32-6a, that the accelerating electrode is connected to the positive terminal of the high-voltage power supply. Although electrons are accelerated towards the accelerating electrode, the object is to get them past it, to the screen. The speed of the electrons is made high enough to keep them moving past the accelerating anode to the screen. The speed at which the electrons travel increases continuously as they get closer and closer to the anode. The average velocity depends on the amount of voltage between anode and cathode. The anode is not an open cylinder, as you might expect. If it were, the electrons traveling through it would spread over a large part of the screen, producing a large area of illumination on it. What is wanted on the screen is a *small spot* of light, because such a spot provides a sharper, better-defined light image on the screen. Therefore the accelerating anode is a cylinder with a small aperture or opening. The small aperture per-

mits a relatively narrow stream or beam of electrons to pass through it, resulting in a small spot of light on the screen of the tube.

A rudimentary cathode-ray tube similar to the one we have just been considering was used many years ago in the study of electric and magnetic fields. The electron beam in the CRT was deflected by the electric and magnetic fields, causing the spot of light produced on the screen by the beam to move about. The movements of the spot provided information regarding the strength and direction of the fields.

A Modern CRT. The elementary tube we have just described provided no means of moving or deflecting cathode rays in accordance with applied a-c voltages. The modern CRT makes such provisions; it also offers other improvements as well.

A modern tube has electrodes that do the following:

1. Form an electron beam.
2. Accelerate the electrons in the beam toward the screen.
3. Focus the beam in order to produce a sharp spot of light on the screen.
4. Deflect the spot of light in such a way that the waveform of the a-c voltage applied to the input of the oscilloscope is reproduced.

Cathode-ray tubes used in modern oscilloscopes may be classified on the basis of the means used to deflect the electron beam. Some tubes use electromagnetic deflection. A tube of this type has a coil located around its neck. Current sent through this coil produces a magnetic field that deflects the beam. Other tubes use electrostatic deflection. In such tubes, suitable voltages are applied to electrodes inside the tube. Most oscilloscopes used by servicemen employ electrostatic deflection. So we will not discuss electromagnetic deflection further.

Electrostatically Deflected C-R Tube: General Structure. The group of electrodes

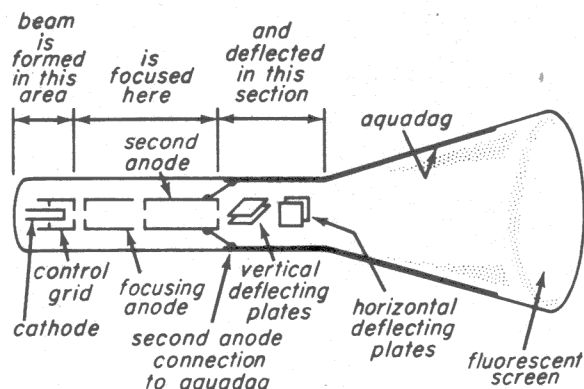


Fig. 32-7

used to form and focus the electron beam and accelerate electrons in the beam toward the screen is known as the *electron gun*. A typical gun consists of a heater, cathode, control grid, focusing anode, and high-voltage accelerating anode known as the second anode (Fig. 32-7). A simplified cross-section drawing of an electron gun is shown in Fig. 32-8.

Two sets of deflection plates are used to deflect the beam. One set of plates is used to produce horizontal deflection; the other set produces vertical deflection.

A chemically-treated screen on the surface of the CRT emits light or *fluoresces* when it is struck by beam electrons. This fluorescent effect is used to make waveforms visible on the screen.

The final important element in the CRT is the *aquadag coating*. This is a conductive coating laid down along the inside surface of the glass bell of the tube and extending almost to the screen. The aquadag connects to the high-voltage anode and is therefore at the same high potential as this anode. The aquadags collect electrons that are knocked off the fluorescent screen by the beam electrons that bombard it. The *secondary electrons*, as we may call the electrons knocked off the screen, flow through the high-voltage power supply to the cathode of the CRT.

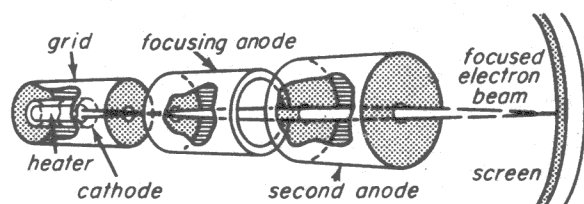


Fig. 32-8

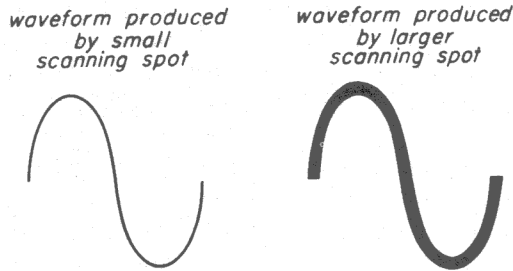


Fig. 32-9

If the aquadag were not used, the accumulation of secondary electrons in the vicinity of the CRT screen would, as a result of its repelling effect, slow down oncoming beam electrons, and thus reduce the illumination of the screen, since screen illumination is proportional to the velocity as well as the quantity of electrons striking the screen.

Focusing Action of Electron Gun. The electron gun (Fig. 32-8) as we pointed out in a preceding paragraph, forms, focuses, and accelerates the electron beam. Even though the beam goes through a small aperture, this aperture is not small enough to produce a thin beam. If the aperture were small enough to produce a beam of the required thinness, so few electrons would get through that the beam would not be strong enough to produce an *adequately bright spot*. This is so because the light given off by the screen is proportional to the number of electrons bombarding it.

Any aperture through which the beam passes must, therefore, be made large enough to allow a relatively thick beam to pass through it. This beam is converged or brought to a point at the screen through the action of the focusing fields referred to in a preceding paragraph.

This focusing results in a very small, round spot, or *scanning spot*, as it is known. This spot is required in order to produce a sharply-defined waveform image on the face of the cathode-ray tube. If the spot is large, the outline of the waveform will be so thick that it will be hard to tell what its real shape is like (see Fig. 32-9). If the spot is too large, no waveform at all can be traced out; think of trying to draw a waveform three inches high with a pencil point four inches in diameter, and you'll realize why this is so.

Proper focus is obtained through the action

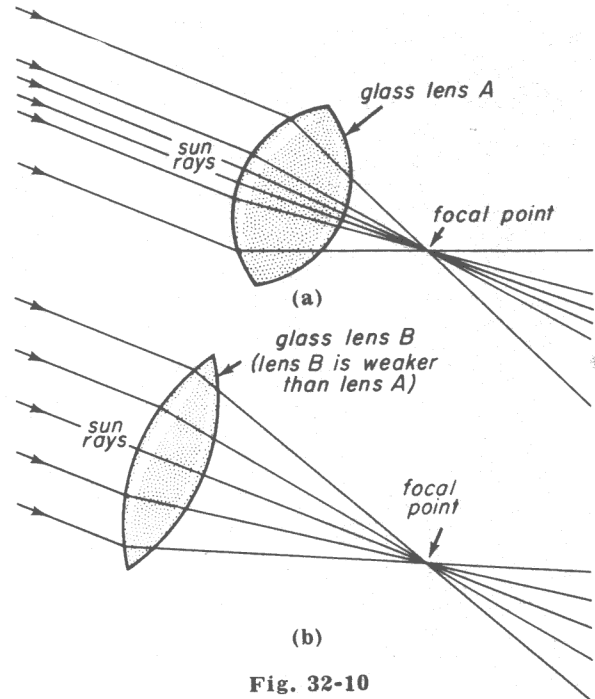


Fig. 32-10

of electrostatic fields. These fields are set up by applying suitable voltages to different electrodes in the cathode-ray tube. We can compare the electrostatic focus system by which the beam is focused to optical focusing. A simple optical lens is shown in Fig. 32-10a. Note that parallel rays of light at the edges of the beam are bent by the lens. The rays of light converge at the *focal point*. If a weaker lens is used, as shown in Fig. 32-10b, the focal point is farther from the lens.

In Fig. 32-11a, two groups of lenses are used for focusing. Let's follow the beam of light as it passes through this system. The rays of light from the light source pass through a small aperture. The light comes through the aperture as a beam. The beam goes through lens A, which causes the light rays to converge at a point just beyond another aperture. The light rays start to spread out, are narrowed by the second aperture, after which they start to spread out again. A second lens causes the beams to converge again. The focal point of the beams is the screen itself. The entire focusing system, is necessary in order to cause the light from the source to reach the screen as a sharply focused beam. The system used is very similar to the electrical-lens system used in the CRT, as shown in

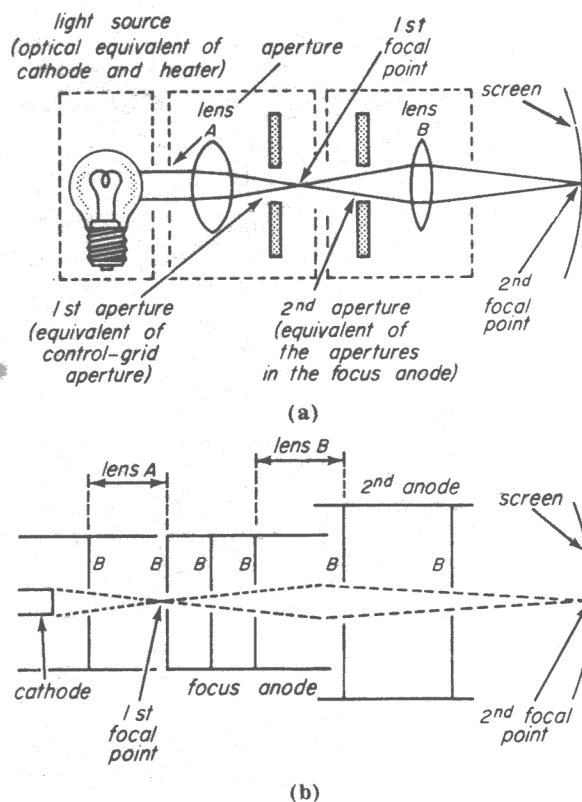


Fig. 32-11

Fig. 32-11b. Instead of using optical lenses to focus the beam, the CRT uses electrostatic fields.

Notice the lines marked B in the drawing. These lines represent walls, or *baffles*, in the electrodes of which they are a part. Each of these baffles has an aperture in its center so that electrons can pass through it. For the sake of simplicity, all these baffles were not shown in Fig. 32-8. But by comparing Fig. 32-8 with Fig. 32-11b you can get an idea of where these baffles are. For example, the baffle at one end of the focus anode is shown in both illustrations; however, the two baffles in the center portion of the focus anode are not shown in Fig. 32-8.

The desired electrostatic fields are produced by suitable construction and spacing of CRT electrodes and the application of proper voltages to these electrodes. Two electron lenses instead of one are required because one lens will not provide sufficiently good focusing. The first lens helps narrow the beam to a point where the focusing action provided by the second is satisfactory.

The focusing can be adjusted by varying the voltage applied to the focus anode. This voltage is varied by a potentiometer. On the RCA Cathode-Ray Oscilloscope, Type WO-78A, which is illustrated in the Appendix to this lesson, this potentiometer is called the **FOCUS control**. The strength of both electron lenses is varied when the focus anode voltage is changed. As a result, there are corresponding changes in both focal points of the beam. If the second focal point is not on the screen, it can be made to fall on the screen by adjusting the focus potentiometer.

Accelerating Action of Electron Gun. The amount of light given off by the fluorescent screen is proportional to the speed as well as the number of electrons striking the screen. The speed of the electrons depends largely upon the acceleration imparted by the second, or high-voltage, anode. The first or focus anode also speeds up the beam, since it is at a positive potential with respect to cathode. Some electron guns have an electrode called a *screen grid*. This added electrode, which is connected to the second anode and therefore has the same high voltage as the second anode provides additional acceleration (as well as better focusing).

Effect of the Control Grid. The *control grid* (Fig. 32-12 shows its relative position) is used to help focus the beam as well as provide a means of controlling the number of electrons in it. The control grid is kept at a voltage negative with respect to the cathode. Thus, the CRT is negatively biased. By means of changing the grid-to-cathode voltage of the CRT, the electron flow through the tube is made to vary. As a result, there is a variation in the number of electrons that reach the screen of the tube; therefore the brightness of the spot on the screen

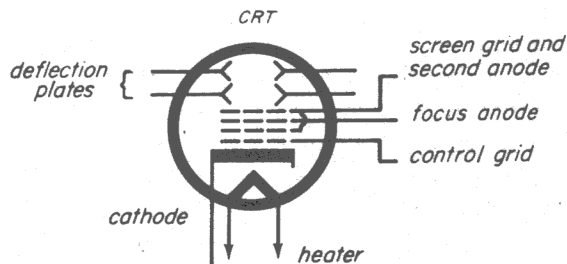


Fig. 32-12

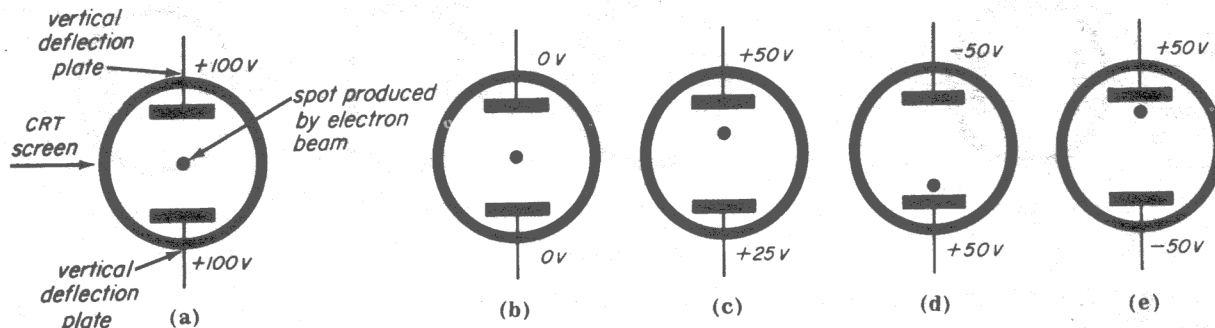


Fig. 32-13

varies. It is useful to be able to vary the brightness of the beam on the screen. When general lighting of a room changes, it causes the apparent brightness level to become too high or too low; the proper brightness can be restored by means of varying the brightness control voltage. On the oscilloscope shown in the Appendix, the control used for this purpose is labeled OFF-INTENSITY. The control shaft also turns the oscilloscope on and off.

When the bias of the CRT is made high enough, so few electrons get through to the screen that the screen remains dark. Then the tube is said to be cut off.

Electron-Gun Elements. The focusing and accelerating electrodes are sometimes called *anodes*. An anode is a tube element that attracts electrons because of its positive potential with respect to the cathode. The focusing electrode is also called the focus anode, anode No. 1, or just A_1 . The accelerating electrode is called the accelerating anode, anode No. 2, or simply A_2 . These elements are usually drawn as grids on schematic diagrams, as shown in Fig. 32-12. In tube manuals, all the tube elements in the electron gun following the cathode may be shown as grids and designated G_1 , G_2 , G_3 , and G_4 , respectively.

Electron-Beam Deflection. Let's begin our discussion by considering the effect on the electron beam of applying d-c voltages to one set of deflecting plates — the vertical deflection plates. We'll begin by applying equal d-c voltages between each vertical deflecting plate and ground. Since both plates have identical charges, each plate will attract the electron stream to the same extent. Since the electron stream is midway between the plates, the attracting

forces cancel each other. This is true regardless of whether the d-c voltages are positive or negative. Therefore the beam will not be attracted to either plate. It will stay centered between the plates (Fig. 32-13a). A similar condition exists when there is no d-c voltage applied to either plate (Fig. 32-13b).

But when the d-c voltage of one plate is made more positive than the other one, the beam will move toward the more positive plate (Fig. 32-13c). If the voltage of the top plate is *negative* and that of the bottom plate is *positive*, the negative plate will repel the beam, at the same time that the positive plate is attracting it. As a result, the beam will move downward (Fig. 32-13d). If the voltages are reversed (Fig. 32-13e), the direction of motion of the beam reverses. The up-and-down movement of the beam is called *vertical deflection*. The plates that deflect the beam up and down are called the *vertical deflection plates*. The RCA Cathode-Ray Oscilloscope, Type WO-78A (See Appendix), has a V CENTERING control for controlling the d-c voltage applied to the vertical deflection plates

Horizontal or side-to-side deflection is also used in the oscilloscope. The plates that perform this function are called the *horizontal deflection plates*, and the control (see Appendix) is called the H CENTERING control. The effects of applying d-c voltages to the horizontal deflection plates are illustrated in Fig. 32-14. The deflection produced is similar to the deflection that takes place vertically, except that its direction is from side to side, instead of up and down. In both vertical and horizontal deflection, the amount of deflection is proportional to the amount

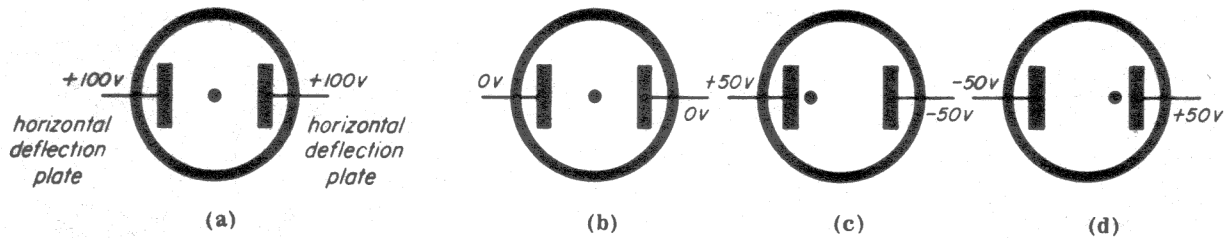


Fig. 32-14

of d-c voltage difference between a set of plates. The larger this difference, the greater will the deflection produced (see Fig. 32-15).

We have been considering *static* deflection; that is, a d-c voltage deflects the beam to a certain position and *leaves it there*. The beam remains motionless after it has been deflected, provided the d-c voltage difference between the plates remains unchanged.

Both sets of deflection plates are located just beyond the second anode. They are flared (bent outward) at their ends, so that the beam will not strike them even when it is at maximum deflection (Fig. 32-16). The plates are identified by standard numbers in tube manuals, manufacturers' tube specification sheets, schematic diagrams, etc. The horizontal plates are designated DJ_1 , and DJ_2 . In older tube manuals and schematics, the same plates may be labeled simply D_1 and D_2 . The vertical plates are designated DJ_3 and DJ_4 (or D_3 and D_4).

Figure 32-17 illustrates what happens if d-c voltages are simultaneously applied to *both* sets of deflection plates. In *a*, the spot is not deflected. If the two d-c voltages are equal, and the voltages exert forces in the beam in the directions indicated by vectors OX and OY in Fig. 32-17*b*, the beam will be pulled with equal force in two directions—*toward the right, and up*. Its path will neither be directly right or up, but midway between both directions as shown by vector OZ .

If the d-c voltages applied to the vertical and horizontal deflection plates are unequal, the direction the scanning spot (spot of light produced by the beam) will take can be shown with vectors (Fig. 32-17 *c* and *d*). The length of each vector arrow is proportional to the d-c voltage applied to each pair of deflecting plates. The resultant can be found by drawing a parallelogram using the vectors as two of the sides, sketching in the other two sides, and drawing a diagonal between

opposite corners. The results show the direction of the electrostatic pull. The length of the diagonal indicates the amount of deflection that will take place.

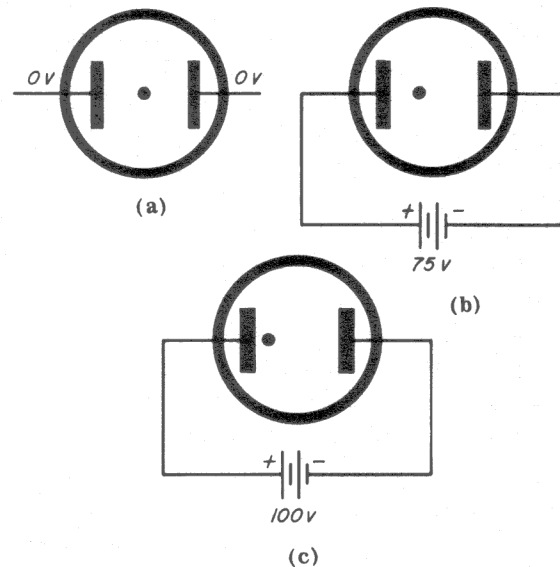


Fig. 32-15

When the d-c voltage difference between each set of plates is zero the beam will not be deflected at all but will remain stationary

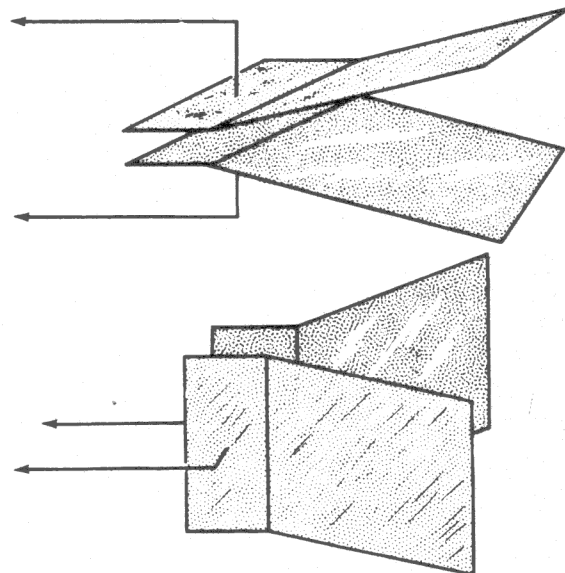


Fig. 32-16

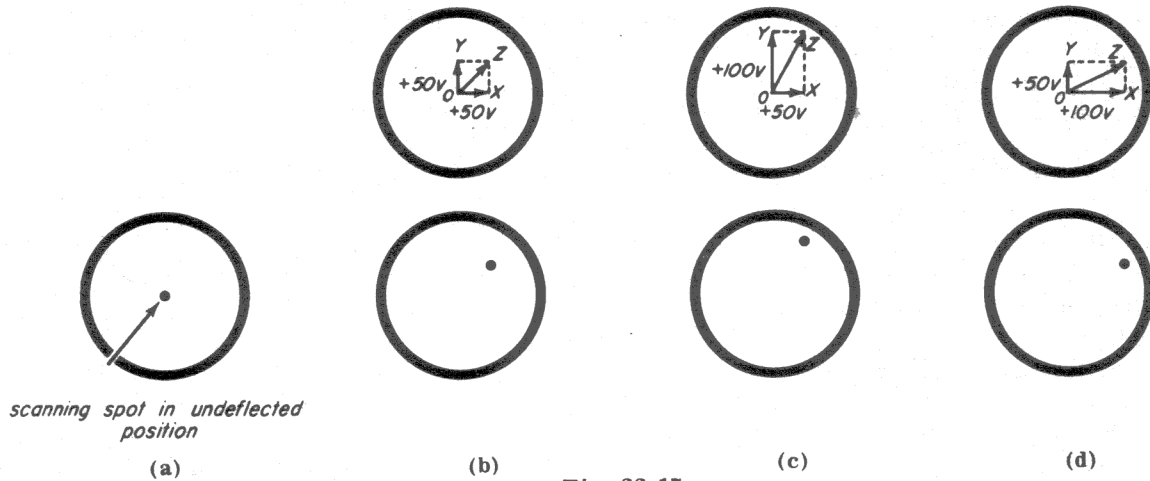


Fig. 32-17

in the center of the screen. Such a condition will exist when no d-c voltages are applied to the plates, or when the d-c voltage applied to one plate of each set is the same (in polarity as well as amount) as the d-c voltage applied to the opposite plate. In the last-named case, the reason the beam remains stationary is that the forces that tend to make it move completely cancel out.

Now let's consider what happens when an a-c voltage is applied to a set of deflection

plates. In Fig. 32-18a, an a-c generator is connected to the horizontal plates. The sine-wave a-c voltage on one plate is 180 degrees out of phase with the voltage on the other plate.

At the time indicated by the number 1 in Fig. 32-18b, the applied sine-wave voltage is at the zero level. The beam will be in the center of the screen at this time (point 1, Fig. 32-18c). At time 2, the sine-wave voltage is becoming more positive on plate DJ_1 , and more negative on plate DJ_2 . The beam

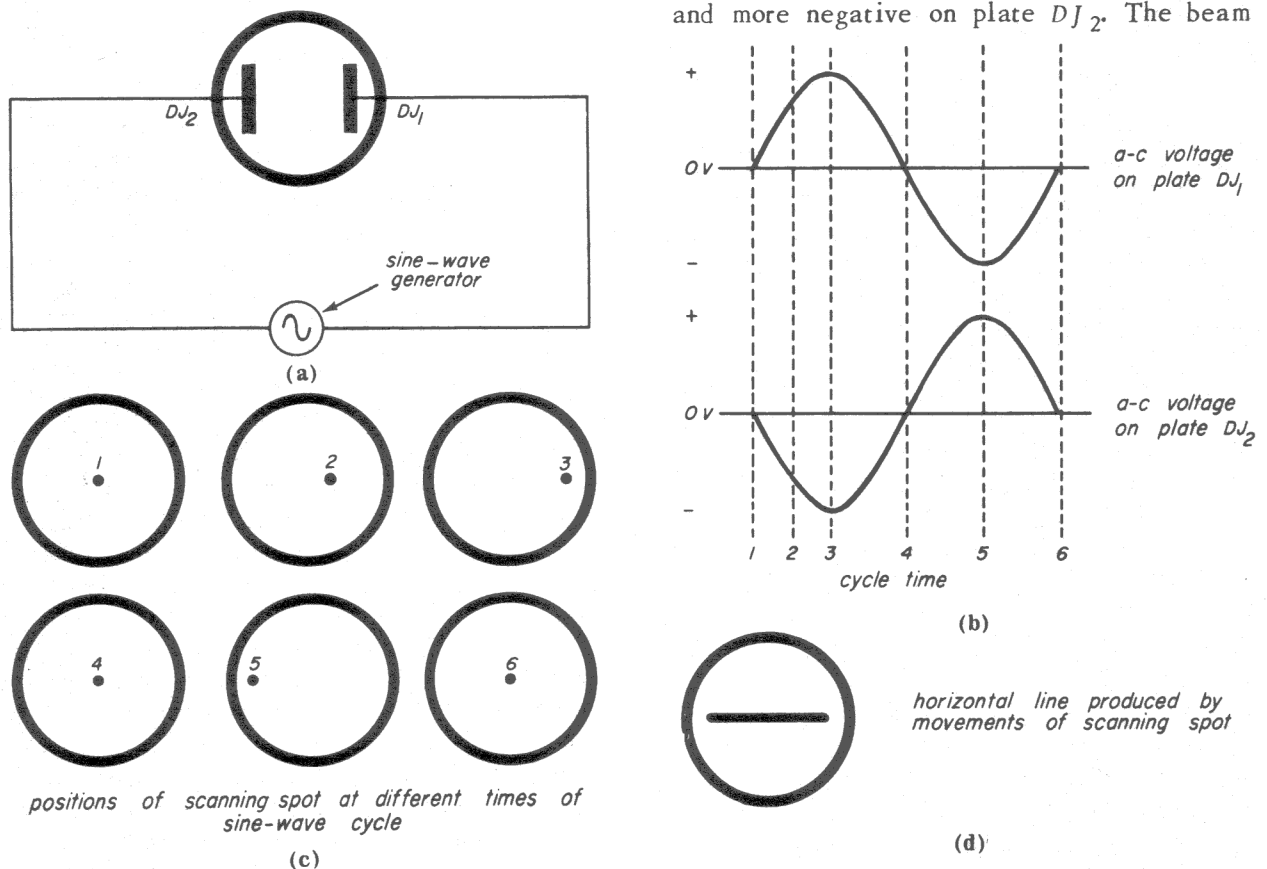


Fig. 32-18

is consequently attracted by DJ_1 , and repelled by DJ_2 ; both forces cause it to move to point 2 on the screen. At time 3 of the sine-wave voltage cycle, the positive voltage on DJ_1 has become maximum; the negative voltage on DJ_2 has likewise increased to its highest value. This means that the electrostatic force tending to deflect the beam toward the left has increased proportionately. The beam, instead of remaining stationary at point 2, as it would have if the voltage difference between the plates had remained unchanged, moves to point 3. At time 4, the sine-wave voltage on DJ_1 and DJ_2 returns to the zero level. The beam no longer has any force acting on it, so it returns to point 1, the center of the screen.

Just after time 4, the forces acting on the beam reverse. DJ_1 becomes negative-going, DJ_2 becomes positive-going, causing the beam to be pulled toward the left, in the direction of DJ_2 . At time 5, the force tending to pull the beam toward the left is maximum. The beam is at the furthest point of its leftward deflection at this time. Between times 5 and 6, the voltage on DJ_1 and DJ_2 is falling back to zero. The forces acting on the beam are therefore also falling to zero, causing the beam to return to the center of the screen. The spot of light caused by the electron beam goes back and forth across the screen. But we do not see a moving spot of light. Instead, we see a trace (Fig. 32-18d). The reason for this is characteristic of human eyesight known as *persistence of vision*. This peculiarity causes us to see light for approximately 1/10 of a second after it has disappeared.

If a spot of light moves across a screen, in less than 1/10 second, the eye will retain the images of all the separate positions of the spots of light and see a horizontal line of light.

In motion pictures, our persistence of vision characteristic is put to good use. Separate pictures are flashed before the eye at a speed greater than 10 times per second. The eye retains the image of one picture until the second one is flashed on the screen, producing the illusion of continuous light and motion.

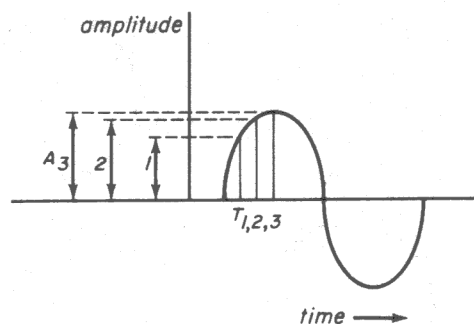


Fig. 32-19

We saw previously that the application of a sine-wave voltage to the horizontal deflection plates produced a horizontal line on the screen. If the sine-wave a-c voltage were applied between the vertical plates, a *vertical* line would be produced. The action is the same as the action in horizontal deflection; only the direction of deflection is different.

Sawtooth Voltage. In actual oscilloscope operation, a voltage that has a *sawtooth* waveshape (resembling the tooth of a saw) is applied to the horizontal deflection plates; the a-c voltage whose waveform is to be checked is applied to the vertical plates. Let's consider why a sawtooth voltage is needed for horizontal deflection.

An a-c voltage varies with respect to *time*. At different *times* in a cycle, a sine-wave voltage will have different amplitudes. In Fig. 32-19, for instance, the amplitude of the sine-wave shown is A_1 at time T_1 ; its amplitude is A_2 at time T_2 , A_3 at time T_3 , etc. You can see that the waveform simultaneously moves in two directions: from left to right along its *time base* or *time axis*, as well as up and down, along its *amplitude axis*. To reproduce such a voltage on the screen of an oscilloscope, we must cause the electron beam to move in two directions at the same time, just as the a-c voltage does; from left to right and up and down.

However, this feature of an a-c voltage did not appear when we discussed what happens when we apply sine-wave voltage to the vertical deflection plates alone. Instead, a straight vertical line was produced in such a case. This is certainly not a picture of the a-c voltage waveform. Although up and down deflection appears, the left-to-right movement

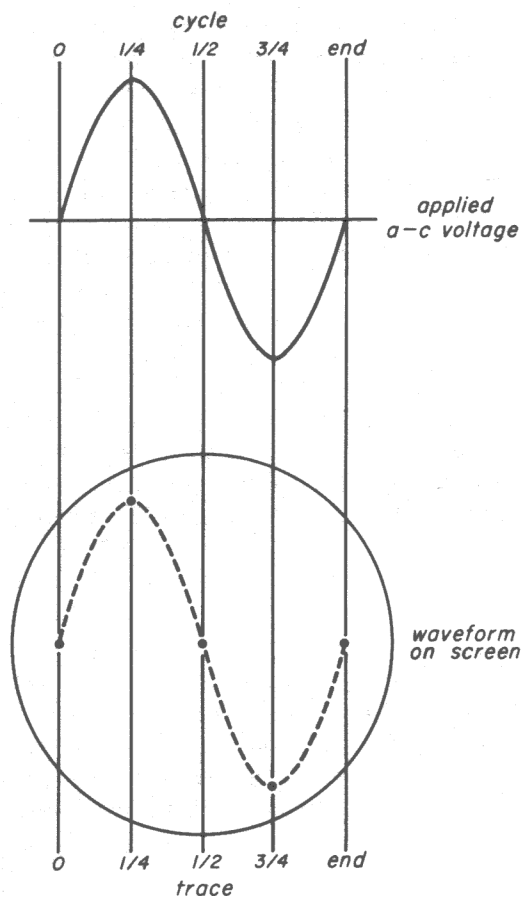


Fig. 32-20

of the waveform, or its movement along its time base, has not been reproduced. By means of applying the correct type of voltage to the horizontal deflection plates, we will be able to produce a better picture of the a-c voltage on the vertical deflection plates.

The horizontal deflection voltage must move the beam from left to right, since it is our custom to read from left to right. To produce the required left-to-right horizontal deflection, the horizontal deflection voltage must be a constantly increasing one so that it will keep the beam moving from the left hand to the right-hand edge of the screen. The value of this voltage must get larger and larger until the beam has been deflected to the right-hand edge of the screen.

Furthermore, the horizontal deflection voltage must *increase at a uniform rate*. If it is desired to reproduce one cycle of an a-c voltage on the screen, the beam must be one-quarter way across the screen when the cycle is one-quarter finished; half-way across the

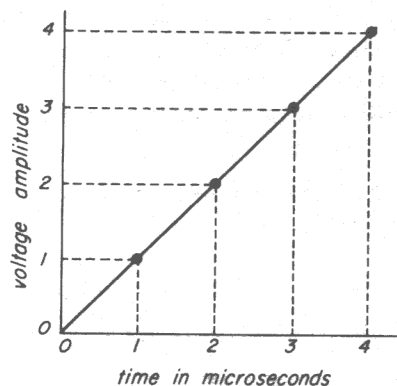


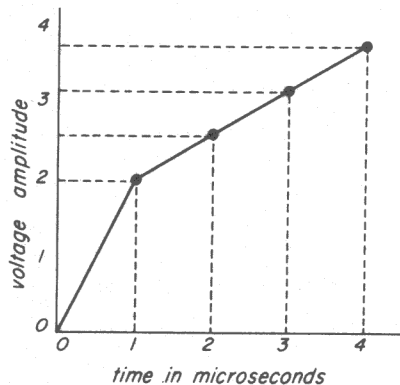
Fig. 32-21

screen when the cycle is half-finished, etc. (See Fig. 32-20). In order to produce such uniform motion, the horizontal deflection voltage must rise in the straight-line manner indicated in Fig. 32-21. Such a uniform rise is called a *linear rise*. In equal intervals of time, equal amounts of voltage are added. Referring to Fig. 32-21, if the voltage is measured at the end of each microsecond interval, we will find that it is 1 volt at the end of 1 microsecond, 2 volts at the end of 2 microseconds, 3 volts at the end of 3 microseconds, etc. This constant increase in voltage is a *linear increase*. Horizontal deflection produced by such a linear increase in voltage is called *linear deflection*.

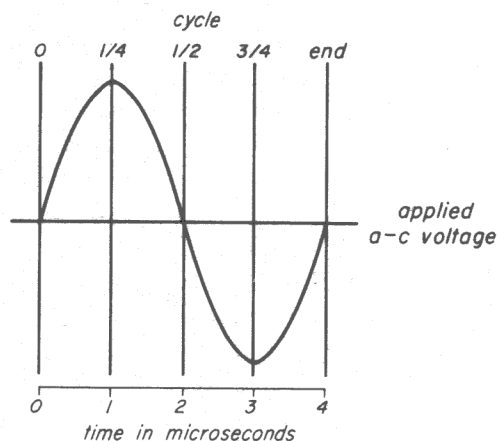
If the horizontal voltage were not linear, the representation of the vertical wave would be distorted. Let us consider what would happen if the horizontal deflection voltage looked like Fig. 32-22a. Although the entire waveform occurs within 4 microseconds, the same time as is required by the waveform in Fig. 32-21, it is not linear. As a matter of fact, during the first 2 microseconds, the voltage in Fig. 32-22a rises twice as fast as the voltage in Fig. 32-21; in the remaining two microseconds, it rises only half as fast. When the sine-wave voltage shown in Fig. 32-22b is applied to the vertical deflection plates of an oscilloscope and the nonlinear waveform of Fig. 32-22a is applied to the horizontal deflection plates, the waveform on the screen of the oscilloscope will look like Fig. 32-22c. During the first microsecond, the horizontal waveform in Fig. 32-22a rises to 2 volts, which is the level required to bring the waveform to the center of the screen of the os-

cilloscope. However, during the same interval, the sine wave can go through only a quarter of its cycle. Therefore a quarter cycle of the sine-wave occupies half of the screen.

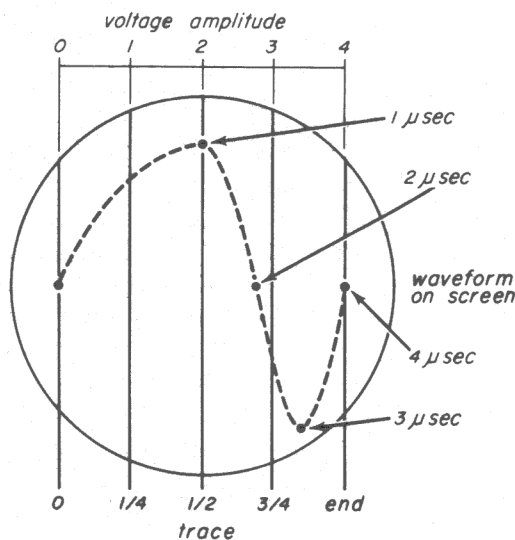
But the horizontal voltage does not continue at this rapid rate. As shown in Fig. 32-



(a)



(b)



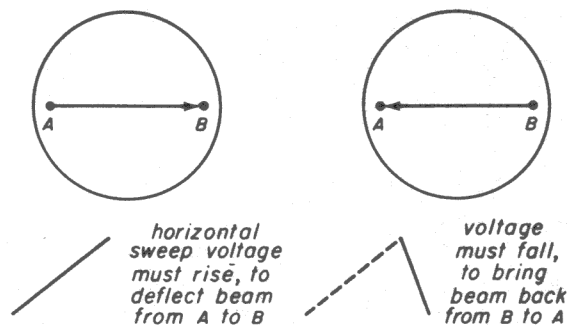
(c)

Fig. 32-22

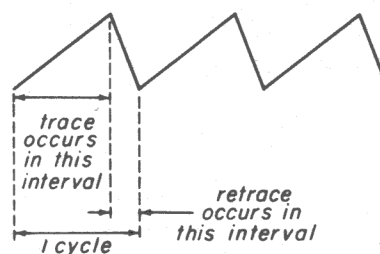
22a, during the last 3 microseconds, the horizontal voltage rises only 2 volts. However, during this time the sine wave goes through three-quarters of its cycle. As a result, three-quarters of the sine wave appears on the other half of the screen. Thus, three times as much of the sine wave is made to appear on the right side of the screen as is made to appear on the left side of the screen. The result is a distorted wave that does not look like the sine wave applied to the horizontal plates. From this example, you can see that the horizontal deflection voltage must be linear if you wish to reproduce the waveform applied to the vertical deflection plates on the screen of the oscilloscope.

Also, horizontal deflection voltage must allow the beam to return from the right-hand edge to the left-hand edge of the screen. This requires that the deflection voltage reverse itself, or fall, when the beam has reached the right-hand edge of the screen (see Fig. 32-23a). When the voltage reversal has brought the beam back to the left-hand edge of the screen, the voltage must be made to rise again and repeat its cycle.

The interval in which the beam moves from the left to the right-hand edge of the screen is called the *trace* interval (see Fig. 32-23b).



(a)



3 cycles of horizontal deflection voltage

(b)

Fig. 32-23

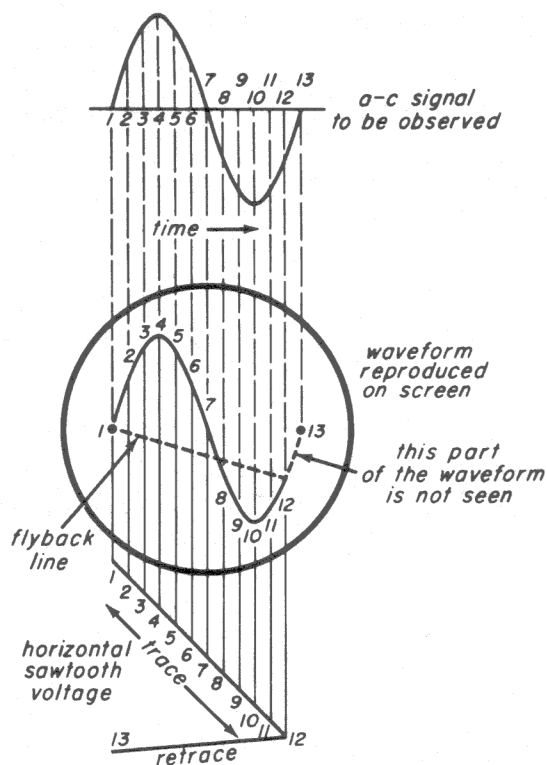


Fig. 32-24

The retrace interval is kept short, compared to the trace interval because the beam is not doing useful work at this time. Ideally, the retrace time should be zero. Under such conditions, the beam would at all times follow the variations of the a-c voltage applied to the vertical deflection plates without taking time out for retrace purposes.

If the retrace time were zero, the beam would start a new cycle as soon as the preceding one was complete. Consider Fig. 32-24, which shows what takes place at different times in the cycle of an a-c sine-wave signal applied to the scope. At time 1 of the a-c signal cycle, the horizontal sawtooth voltage is at point 1 of the trace, and the waveform reproduced on the scope is at point 1 on the screen; at time 2 of the a-c signal cycle, the horizontal sawtooth voltage is at point 2 of the trace, and the waveform on the scope screen is at point 2, etc.

Ideally the sine-wave a-c signal applied to the vertical deflection plates should appear on the screen as going beyond time 12. However, at time 12, the sawtooth stops tracing and starts retracing. The interval between 12 and 13 is needed to complete the retrace.

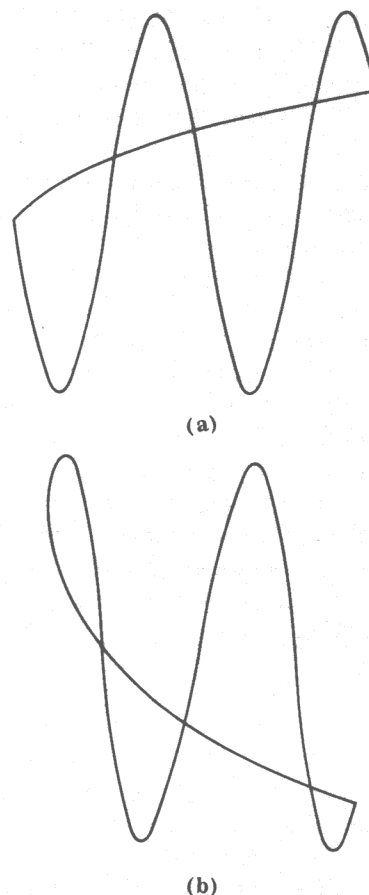


Fig. 32-25

Therefore section 12 to 13 of the sine-wave a-c signal is not reproduced on the scope. The waveform is incomplete. If the retrace time is excessively long, that is, if too large a proportion of the a-c signal is not reproduced on the screen, the portion of the waveform that is missing will be large enough to prevent an adequate check of the waveform shape.

During the retrace time, the beam appears as a line of light on the screen. This line is referred to as the scope *flyback*. It is an undesired addition to the waveform seen on the screen, and is *blanked out* (made invisible) in better grade oscilloscopes.

Figure 32-25a illustrates the actual appearance of waveforms reproduced on the scope when the retrace is normal, and, Fig. 32-25b shows the waveforms when the retrace is excessively long. The line going from the end of the second waveform to the beginning of the first is the flyback. Note how much more distorted the first waveform looks in b than in a.

The longer the retrace, the brighter is the reproduction of the retrace. This is so because the amount of light seen on the screen is proportional to the speed of the beam. When retrace is rapid, compared to the trace, the flyback line will be rather faint compared to the trace, and will not interfere too greatly with the appearance of the waveform on the screen. When the retrace is slow (when the retrace time approaches the trace time) the brightness of the flyback approaches the intensity of the trace. The flyback will mar the waveform, making it difficult to determine its true shape.

An excessively long retrace is objectionable even when the retrace is blanked out by *retrace blanking circuits*. The longer the retrace is, the less efficient is the action of these blanking circuits in making the flyback invisible.

Now that we have discussed in general how the horizontal and vertical deflection of the beam operate, let's consider the subject in a little more detail. Assume that the sawtooth voltage applied to the horizontal set of plates has the same frequency and roughly the same amplitude as the sine-wave a-c voltage that is being applied to the vertical set of plates. If the *sine-wave voltage* were *not* applied to the vertical deflection plates, the beam, as shown in 32-26, would move straight across the screen from point 1, to point 2, to point 3 etc., during the trace portion of the horizontal deflection cycle. With the sine-wave signal applied to the vertical deflecting plates, the beam is deflected up and down while it is moving toward the right, as shown by the dots at the top of Fig. 32-26.

The amount of vertical deflection is proportional at every instant to the amplitude of the sine-wave signal. The rate of change (i.e., the frequency) of the waveform reproduced on the scope is the same as that of the applied sine-wave signal. The amplitude and frequency characteristics of the sine-wave signal are thus accurately represented on the scope screen.

In the case we have discussed, only one cycle of the waveform to be checked is seen on the screen. This is so because one verti-

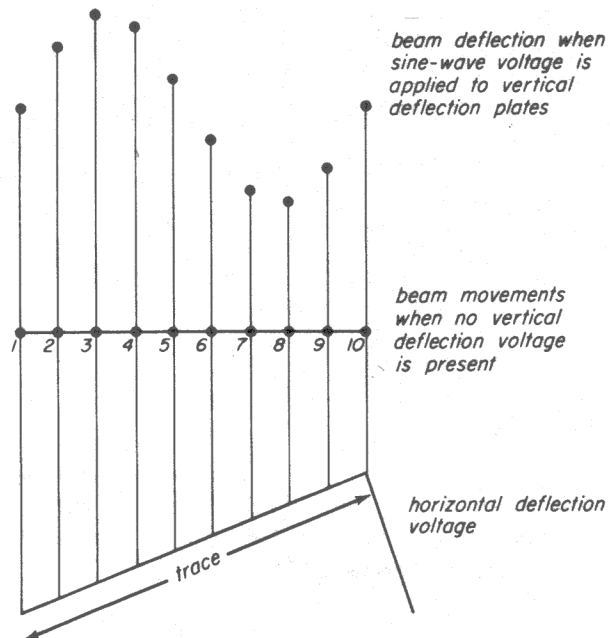


Fig. 32-26

cal cycle takes place in the same time as one horizontal cycle. If the vertical deflection voltage were twice the frequency of the horizontal deflection voltage, vertical deflection would vary at a rate twice as fast as the horizontal deflection voltage, and two cycles of vertical voltage would appear on the screen. If the vertical deflection voltage were three times the frequency of the horizontal voltage, three cycles of vertical voltages would be seen, etc.

The Fluorescent Screen. The fluorescent screen is a chemical coating on the glass surface of the large end CRT. This is a zinc compound that will produce a predominantly green light when it is bombarded by electrons traveling at high speed.

The screen coating has *phosphorescent* as well as *fluorescent* characteristics. Fluorescence, as you have already learned, is the name given to the emission of light by the screen when it is bombarded by electrons. The emission of light by the screen *after* the bombardment has stopped is referred to as *phosphorescence*. The term *persistence* is used to describe the screen's phosphorescent characteristic. A screen that glows for a relatively long period of time after electrons have stopped bombarding it is said to have a *long persistence*. When the afterglow is short, the screen is said to have a *short persistence*.

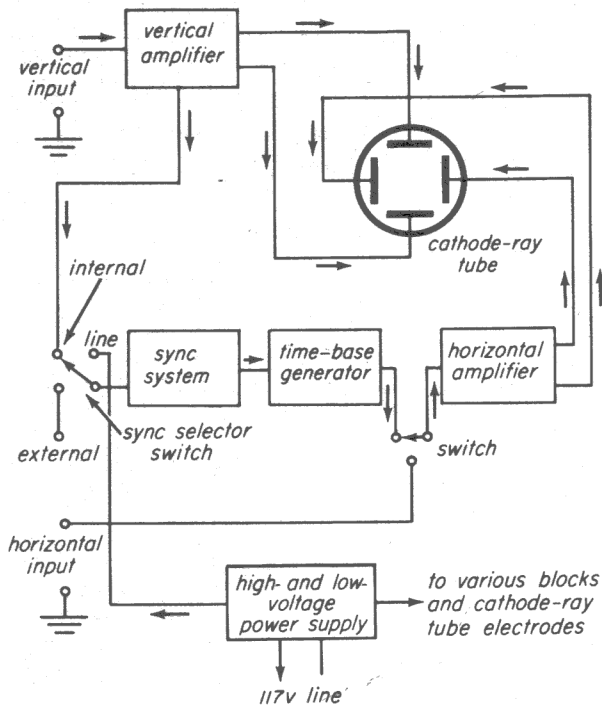


Fig. 32-27

Most servicemen use oscilloscopes that have screens with a long persistence. (In CRT's used in TV receivers, on the other hand, screens with a shorter persistence are desirable, because the image on the screen is constantly changing; a screen with a long persistence would not permit the rapid changes in screen lighting that occur to be clearly apparent.) The types of cathode-ray tubes used in oscilloscopes have screens of different sizes. The commonest diameter is five inches. Other diameters are three and seven inches. The larger the CRT, the easier it is to inspect the waveform image reproduced on its screen.

32-2. OSCILLOSCOPE CIRCUITS

A block diagram of the circuits employed in a representative oscilloscope is shown in Fig. 32-27. We'll discuss the general nature and functions of these circuits in this section of the lesson. In subsequent sections, individual circuits will be described in detail. The a-c voltage to be checked is applied to the vertical input terminals of the oscilloscope. These terminals are labeled V INPUT and GND in the illustration in the Appendix. This a-c signal, as it is known, may not be large enough to produce an adequately large waveform image on the scope screen. There-

fore a vertical amplifier section is incorporated to amplify the a-c signal. After passing from the amplifier, the a-c signal, is applied to the vertical deflection plates of the CRT.

Provisions are made in most oscilloscopes for applying the a-c signal directly to the vertical deflection plates, without passing the signal through an amplifier. Such a connection is necessary when the vertical signal is very large or is outside the frequency range of signals that can be passed by the vertical amplifier.

The horizontal deflection oscillator (also known as the *sweep oscillator*, or the *time-base generator*) generates the sawtooth voltage needed for horizontal deflection. Since the output of the oscillator is not large enough to deflect the beam fully across the width of the CRT, a horizontal amplifier section is employed to boost the oscillator sawtooth voltage output to the proper amplitude. The amplitude of the oscillator sawtooth determines the width of the waveform seen on the screen. On the oscilloscope pictured in the Appendix, horizontal gain is regulated by the H GAIN control.

To improve the stability of the waveform traced out on the screen—that is, to keep the waveform stationary, so it can be inspected—a portion of the vertical amplifier output is fed back to the input of the horizontal oscillator, sometimes directly, in other cases through an amplifier. The signal fed back from the vertical amplifier to the time-base generator is known as the *synchronizing signal* (sync signal for short). A sync-selector switch (called SYNC H AMPL on the oscilloscope shown in the Appendix) permits different types of sync signal to be switched in. The SYNC portion of the switch has various settings. At the INT settings, the sync signal comes from the vertical amplifier; at the LINE setting it comes from a 60-cps voltage in the power supply; and at the EXT setting, sync is derived from a source external to the oscilloscope. The external sync is applied to the oscilloscope shown in the Appendix by way of the SYNC and GND terminals. (Refer to the detailed description of switch settings in the Appendix.) You'll learn more about these sync signals when we

discuss synchronization in detail, later on in this booklet.

For certain tests, it is helpful to apply a time-base signal coming from an external source (instead of the oscilloscope's time-base generator) to the horizontal-deflection plates. A switch is provided (the H AMPL portion of the SYNC H AMPL switch shown in the Appendix) for this purpose. The external horizontal sweep voltage source is connected to the *horizontal input* terminals (labeled H INPUT and GND in the Appendix). The H AMPL switch is set so as to disconnect the oscilloscope time-base generator from the horizontal amplifier, and the external source of sweep voltage is connected to the amplifier instead. You will learn more about external sweep voltages later on.

A terminal block is located at the rear of many oscilloscopes (Fig. 32-28). Connections to the deflection plates are made accessible here. The block makes it possible to rapidly disconnect the deflection plates from the amplifiers with which they are associated, in cases where it is desired to feed signals directly to the plates.

The high-voltage power-supply generates the high d-c voltage needed to accelerate the electron beam. The low-voltage power supply provides the B+ voltages needed by the time base generator, horizontal and vertical amplifiers, and sync amplifier (when such a stage is used).

The CRT, as we already know, forms, accelerates, focuses and deflects the elec-

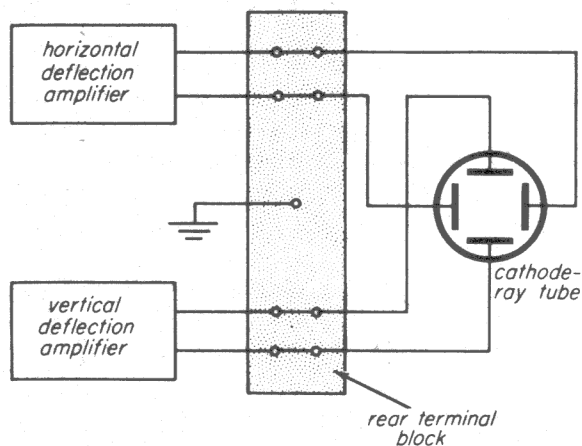


Fig. 32-28

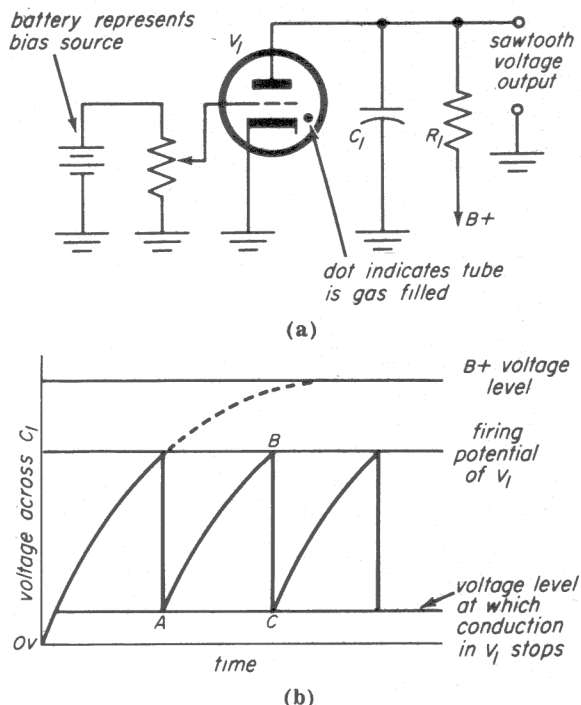


Fig. 32-29

tron beam, causing the applied a-c voltage to be reproduced on its screen.

32.3. THE TIME-BASE GENERATOR

The time base or horizontal sweep generator, as we mentioned earlier in this lesson, is used to create a sawtooth voltage for horizontal deflection purposes. In some oscilloscopes, a type of oscillator known as a *thyatron sawtooth generator* is used to produce the required sawtooth voltage. A simplified circuit that illustrates the principle of the operation of a thyatron sawtooth oscillator is shown in Fig. 32-29a.

A thyatron is a triode tube filled with argon gas. Current cannot flow between cathode and plate unless the gas becomes ionized. When the plate voltage exceeds a certain minimum level, the gas ionizes, and the tube becomes highly conductive. The value of plate voltage needed to cause ionization of the gas is known as the *break-down potential*, or the *firing voltage*. If the plate voltage falls beyond a certain minimum when the tube is conducting, the thyatron will stop conducting.

The grid bias of the tube helps determine the firing point of the thyatron. The more

negative the bias, the higher the value of plate voltage required to fire the tube, and vice-versa. As soon as the tube conducts, the grid loses all control of plate current.

A capacitor, C_1 is connected between the plate of the thyatron and ground. Therefore the positive side of the capacitor and the plate of the thyatron are at the same potential. When B^+ is applied to the tube, through resistor R_1 the capacitor charges up; the plate of the thyatron and the positive side of the capacitor become more and more positive. The rate at which the capacitor charges depends on the time constant of R_1 and C_1 . When the plate of the tube becomes sufficiently positive, the gas in the tube ionizes. Therefore the tube conducts; current flows from cathode to plate.

When current is flowing in the tube, the cathode to plate resistance of the tube is very low. Therefore C_1 discharges through the tube. As a result, the positive side of C_1 and the plate of the thyatron become less positive. The tube becomes nonconducting. Then the cycle begins again. A sawtooth voltage is produced across C_1 during the capacitor's charge and discharge (refer to Fig. 32-29b). The trace portion of the sawtooth (A to B) is developed when V_1 is nonconducting and C_1 charges; the retrace portion (B to C) occurs when V_1 conducts and C_1 discharges. Since the rate of charge and discharge of C_1 depends upon the time constant of R_1 and C_1 , the frequency of the sawtooth produced by the simplified thyatron shown in Fig. 32-29a depends upon the time constant of R_1 and C_1 . The charge built up across C_1 increases at a fairly linear rate (refer to Fig. 32-29b) if the capacitor is not permitted to charge over the entire charging curve.

Another time-base generator called a multivibrator is also used in oscilloscopes to create the horizontal sawtooth signal. When you study television circuits, you will learn about the action of this circuit in detail. But

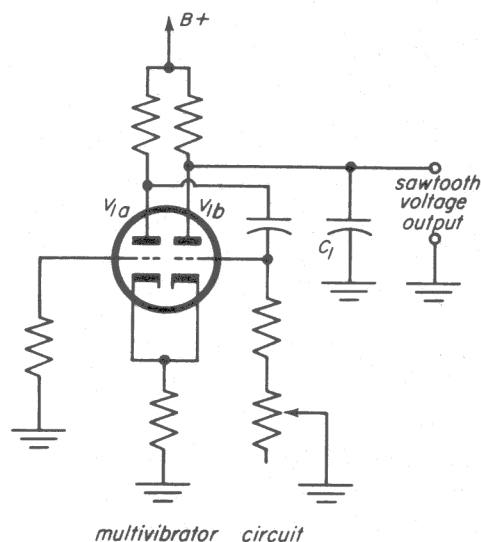


Fig. 32-30

let's consider the over-all action of the multivibrator. A typical multivibrator circuit is shown in Fig. 32-30. V_{1a} and V_{1b} comprise a duo-triode tube. The two halves of the tube conduct. When V_{1a} conducts, V_{1b} is nonconducting and C_1 charges, forming the trace part of the sawtooth. When V_{1b} conducts, C_1 discharges through V_{1b} , forming the retrace. The effect of the multivibrator on charge-discharge capacitor C_1 is, thus, essentially the same as that of the thyatron. A sawtooth voltage is created across the capacitor in either case.

Varying the Frequency of the Time Base Generator. The sawtooth voltage developed by the time-base generator (sometimes called the horizontal oscillator) must be at or near the frequency of the a-c signal applied to the vertical deflection plates.

If the horizontal-oscillator frequency is higher than the a-c signal applied to the vertical deflection plates, the oscillator scans the width of the screen before the vertical signal has completed a cycle. In Fig. 32-31, the horizontal-oscillator frequency is three times the a-c signal frequency. One horizontal sweep cycle is finished when the vertical signal is at point B of its cycle. The beam returns to the left hand side of the screen while the vertical signal goes from B to C; the beam then goes through one more horizontal sweep in the time the waveform goes from C to D. And so it goes, with successive fractions of the ver-

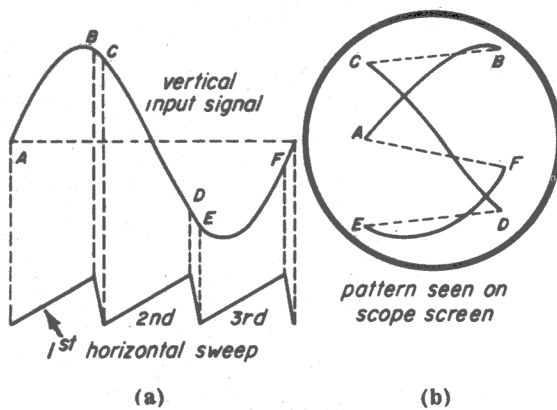


Fig. 32-31

tical signal being traced out during the horizontal sweep cycles following this one. Line A-B is produced in the 1st horizontal sweep cycle, line C-D during the 2nd, and E-F during the 3rd. Dotted line B-C represents the 1st retrace, D-E the 2nd and F-A the 3rd.

If the horizontal-oscillator frequency is very much *lower* than the vertical signal frequency, the vertical signal will complete *many* cycles before the beam has swept across the width of the screen *once*. The waveform image will contain many closely-spaced waveforms in such a case; above a certain vertical signal frequency, the waveforms will be so closely packed that only a blur will be seen on the screen.

However, it is useful to be able to vary the frequency of the output of the horizontal oscillator. For example, if you want to check two cycles of a-c signal, you can do so by making the horizontal oscillator frequency half as great as the a-c signal. If you want to check three cycles of a-c signal, you can do so by making the horizontal oscillator frequency one third as great as the a-c signal frequency, etc. (See Fig. 32-32).

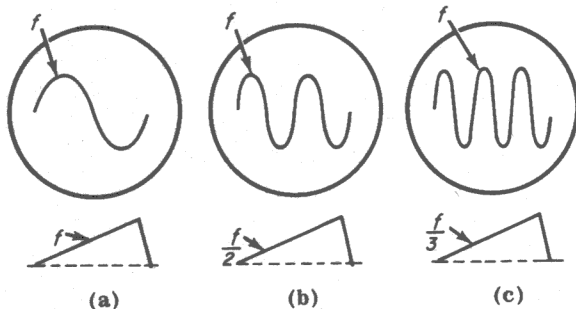


Fig. 32-32

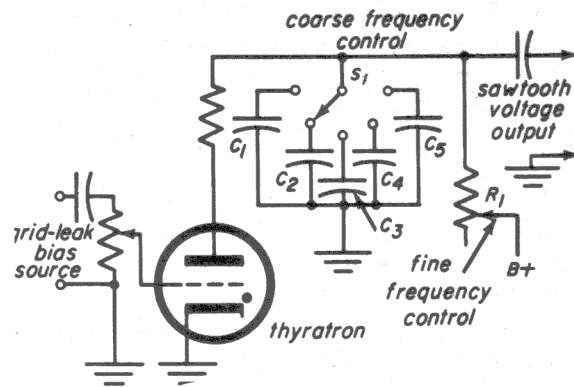


Fig. 32-33

If a thyatron is used as a horizontal oscillator, the frequency of the horizontal oscillator output can be varied by altering the RC time constant of the circuit, as shown in Fig. 32-33. Instead of having only the fixed resistor and fixed capacitor of the circuit we discussed when we first considered the thyatron, this practical circuit has provision for varying both R_1 and C_1 . If the value of R_1 is reduced, C_1 will charge more rapidly causing the sawtooth voltage to rise at a steeper rate (along line A-C in Fig. 32-34a, instead of line A-B). The firing potential of V_1 will be reached sooner; more rapid repetitions of the charge-discharge cycle will occur, and the frequency of the sawtooth voltage rises.

If the value of potentiometer R_1 is increased, C_1 will charge more slowly (along line A-D, instead of A-B, in Fig. 32-34b, since the plate voltage reaches the V_1 fir-

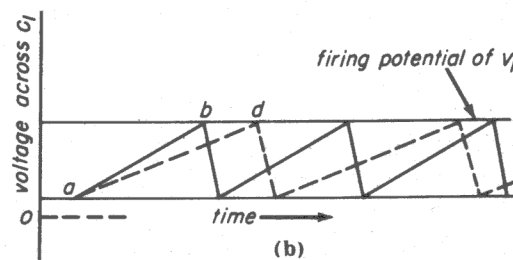
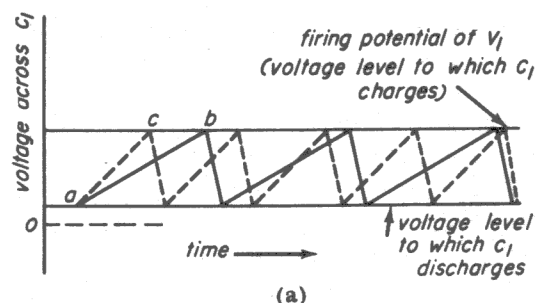


Fig. 32-34

ing level later. Therefore the frequency of the sawtooth voltage becomes lower.

The range of frequencies over which V_1 can be made to operate as a result of varying R_1 is not very great. Larger frequency ranges are made possible by switching in different values of plate-to-cathode capacitance. The smaller the value of capacitance that is switched in between plate and cathode of V_1 , the faster will this capacitance charge, the more quickly will V_1 reach the firing level, and the higher will be the frequency of the generated sawtooth voltage.

The rotary switch (S_1) used to select different values of plate-to-cathode capacitance is known as the *coarse frequency control*, since it controls the frequency of the time base generator in large steps or jumps. R_1 produces small changes in frequency, and is therefore known as the *fine frequency control*. The coarse frequency control is used to bring the horizontal oscillator frequency close to the desired operating frequency. R_1 may then be set to bring the time base generator to the exact operating frequency desired. On the oscilloscope shown in the Appendix, coarse frequency control is provided by the SWEEP control, and fine frequency control is provided by the SWEEP VERNIER control.

Synchronization of Time-Base Generator.

The waveform on the screen of the oscilloscope may move horizontally across the screen instead of remaining stationary. This undesirable condition results from slight frequency differences between the vertical and horizontal signals. These differences are unavoidable, particularly at the higher frequencies.

The result of the difference between the two frequencies is shown in Fig. 32-35. The horizontal sawtooth signal shown completes its first cycle at time 1, slightly before the vertical signal has finished its first cycle. This discrepancy is repeated for each of the five intervals shown. It is assumed that the retrace time is zero, to simplify matters. As shown by the bottom row of illustrations in Fig. 32-35, the portions of the a-c signal swept by the vertical

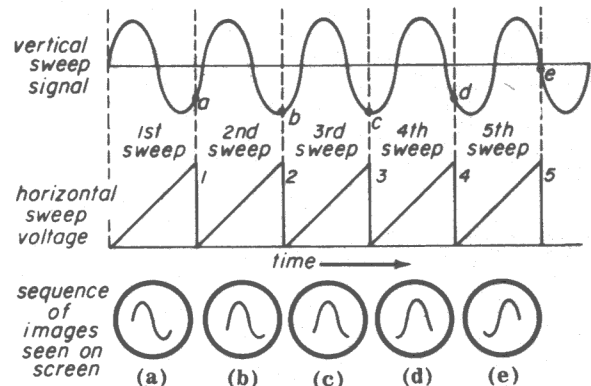


Fig. 32-35

sawtooth are not the same for every interval. Note that the positive peaks of the vertical signal are displaced further and further to the right in each successive sweep. Because the individual images replace each other at such a rapid rate, the waveform image seen on the scope will seem to move toward the right as a result of the displacement of the positive peaks. The speed of this movement depends on the difference between the frequencies of the vertical and horizontal signals. The greater this difference is, the faster will the waveforms travel across the screen.

To correct such undesired movement of the waveform image, a technique known as *synchronization* is employed. A portion of the vertical signal is applied to the input of the horizontal oscillator. This technique causes the horizontal oscillator in the scope to operate at exactly the same frequency as the vertical signal.

The principle involved in synchronization is simple to understand if you understand the effect of the grid bias of the thyatron upon the frequency of the sawtooth output of the thyatron. When the grid is made more positive, less plate voltage is required to make the thyatron fire. In Fig. 32-36a, the grid of the thyatron is shown connected to the INT terminal of the SYNC selector switch.

When the switch is at the INT setting, a portion of the vertical signal is used as the sync signal. When the switch is set to LINE frequency, the sync signal is taken from a 60-cps heater voltage source in the scope; this voltage is, of course, the same in frequency as

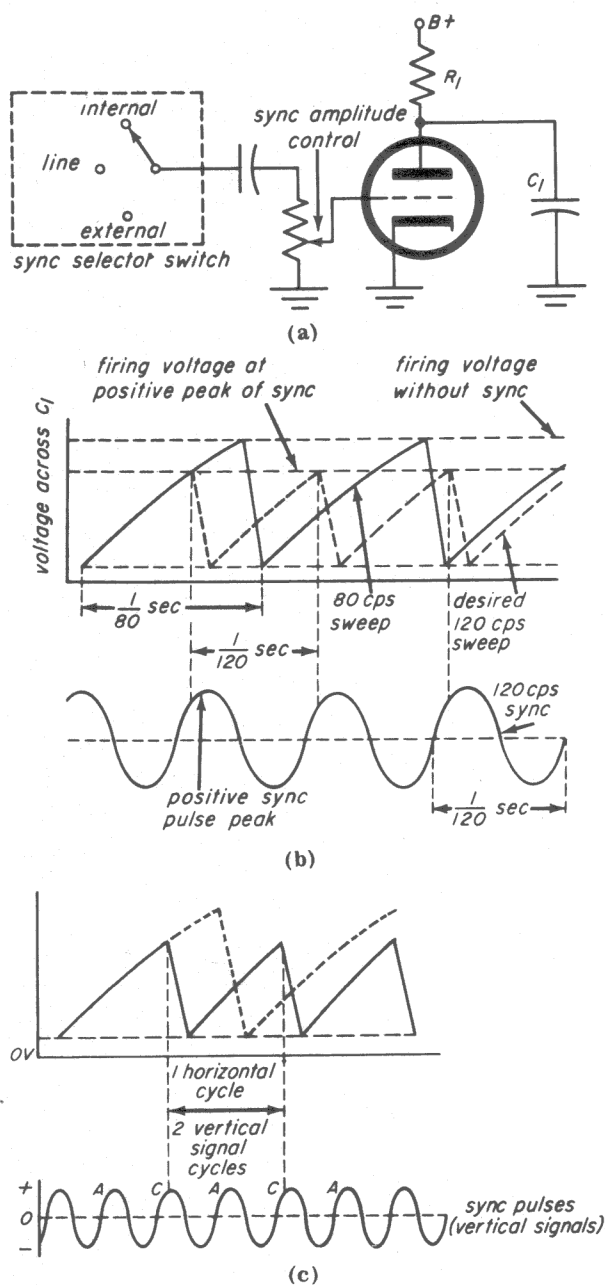


Fig. 32-36

the power line voltage. A synchronization signal of this kind provides best stability when the a-c signal applied to the vertical plates of the scope has a frequency of 60 cps, or some multiple of 60 cps (120, 180, or 240 cps, etc.). Setting the switch to the EXT position permits an external sync signal to be applied to the horizontal oscillator. Application of an external sync signal is desirable in certain cases where the internal sync signal is inadequate to produce proper synchronization, or for other reasons. By means of setting the SYNC switch to INT, a

portion of the a-c signal from the vertical plates is applied to the grid of the thyatron. Therefore the bias of the grid of the thyatron is being varied with the vertical a-c signal. In *b* of the figure, you can see the result of applying this sine-wave vertical signal, called the sync signal, to the grid of the thyatron. The solid-line sawtooth is an 80 cps sweep that is produced by the thyatron when no sync signal is applied to its grid. When 120 cps signal is applied to the thyatron grid, the tube fires at a lower level of plate voltage. Each time the a-c signal is at peak, the positive grid bias is high enough to cause the tube to fire, as shown by the dotted-line sawtooth. Since less time is required for the voltage to reach the level required to fire the tube, the sawtooth frequency increases, in this case to 120 cps.

In the example we have been discussing, the sync voltage was used to lock a single a-c cycle into place on the screen. However, two or more cycles can also be locked into place by the sync. If the difference between the horizontal oscillator frequency and the sine-wave a-c frequency is great enough, more than one sine-wave will appear on the screen of the oscilloscope. This difference can be achieved either by increasing the time-constant of the RC circuit of the thyatron or by actually applying a high sine-wave frequency to the vertical plates, depending upon the purpose you have in mind.

The way in which the sync voltage can be used to lock two or more cycles into place on the screen is shown in Fig. 32-36c. Notice that even though the sync signal reaches peak at points marked A and C, the sawtooth voltage does not rise high enough to trigger the thyatron tube on the points marked A. Only at the points marked C, that is, only at every other cycle of sine-wave a.c. does the thyatron fire. Therefore there is one cycle of sawtooth for every two cycles of sine-wave a.c. As a result, two cycles of sine-wave a.c. are locked on the screen.

In a manner similar to the one described, the horizontal sweep can be locked into step with every *third* sync pulse, to produce three stable vertical signals on the screen, or every *fourth* sync pulse, to produce four stable vertical signals, etc.

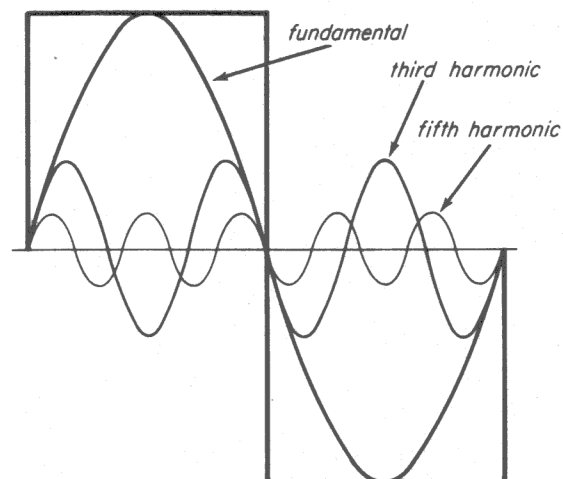
It is important to apply a relatively small amount of sync voltage to the grid of the thyratron. The sync signal develops grid-leak bias for the thyratron. If the applied sync signal is too large, the bias of the thyratron will be reduced so greatly by the positive peaks of the sync signal that the thyratron will fire at the wrong times. Distortion of the vertical signal will result.

32-4. OSCILLOSCOPE AMPLIFIERS

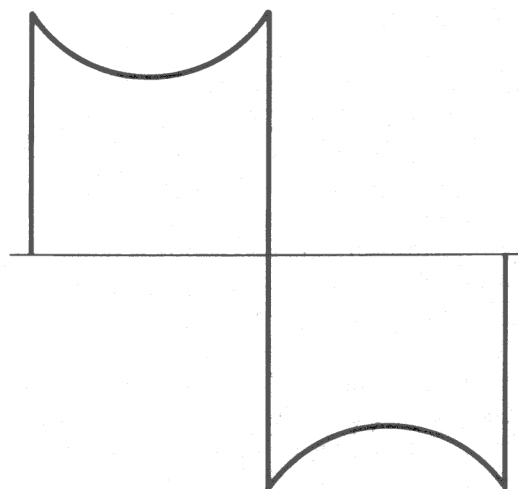
If deflection signals are large enough to produce an image of a size suitable for easy viewing, they are applied directly to the deflection plates without amplification. Deflection signals that are not large enough are sent through amplifier stages. The vertical amplifier increases the size of the waveform in the vertical direction; the horizontal amplifier increases it in the horizontal direction.

The Vertical Amplifier Section. The vertical amplifiers must be able to amplify signals of widely varying frequencies. If the amplifiers were perfect, all input signals would be amplified equally, regardless of their frequency. In practice, there is always an upper frequency limit beyond which the gain of the amplifiers decreases. Most amplifiers also have a lower frequency limit as well, below which their gain also decreases. The range of frequencies that an amplifier will amplify, in a uniform or fairly uniform way is called the *bandwidth* of an amplifier.

A good frequency response is particularly important in cases where square-wave signals are to be reproduced by the oscilloscope. A square-wave signal is made up of many different sine-wave signals that are harmonically related to each other. That is, it consists of a fundamental sine-wave signal whose frequency is the same as the square wave, plus odd harmonics i.e., multiples—of this signal. A few of the harmonics present in a square-wave signal are shown in Fig. 32-37a. (If a fundamental signal is 400 cps, its third harmonic is 1,200 cps, fifth, 2,000 cps, etc.) Unless harmonic signals as far as the 21st are satisfactorily amplified by the amplifier, the square-wave signal will be distorted.



(a)



(b)

Fig. 32-37

Fig. 32-37b shows what will happen to the shape of the square-wave signal when its low-frequency components are insufficiently amplified. Another effect of amplification that is not uniform at all frequencies, is that an accurate determination of a signal's real amplitude may not be possible.

Let's see why this is so. To measure the amplitude of an input signal, its size is compared with that of a signal of known amplitude, called a *test signal*; the frequency of this signal is generally 60 cps.

If the vertical amplifier response is 50% less at 10,000 cps than it is at 60 cps, the 10,000 cps signal will be reproduced at an amplitude 50% smaller than the 60-cps test signal. If the amplitude of the 10-kc signal as measured by the oscilloscope is

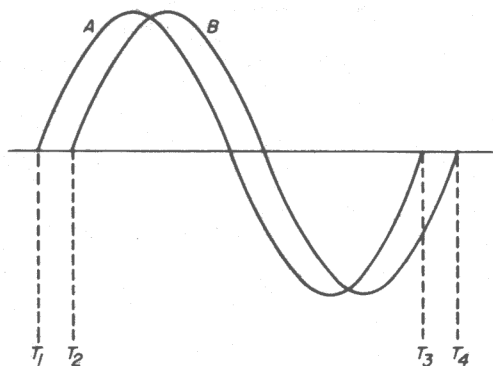


Fig. 32-38

18 volts, its real amplitude will be twice as great, or 36 volts. Another requirement of the vertical amplifier is a uniform phase shift characteristic.

Consider, as an example, *A* in Fig. 32-38. It starts its cycle at time T_1 and finishes the same cycle at time T_3 . If, for some reason, it started a little later—say, at time T_2 —it would finish its cycle at time T_4 . The signal in its delayed form is labeled *B*. This difference is measured in degrees.

If the time a signal starts its cycle is shifted from *A* (Fig. 32-39) to *D*, its normal finish time, we say its phase has been shifted 360 degrees. If the signal starts a half, rather than a full cycle later (or earlier)—say at point *C*, instead of *A*—its phase has shifted 180 degrees. If the signal starts a quarter cycle later or earlier, its phase has shifted 90 degrees, etc.

Phase shift is introduced when a signal passes through circuits that offer it capaci-

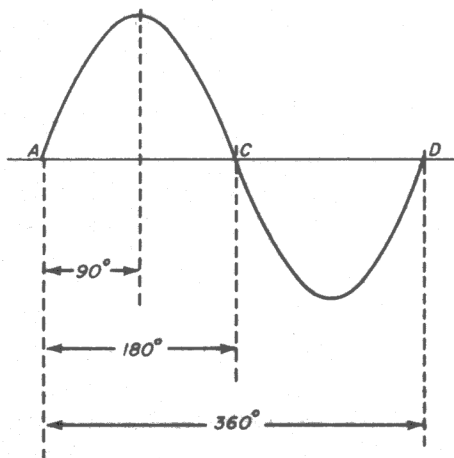


Fig. 32-39

tive or inductive reactance. Phase shift isn't uniform. The same component will introduce different amounts of phase shift for different frequencies, because the phase shift produced depends on the amount of reactance of the signal meets, and reactance varies with frequency.

We can illustrate the objectionable effect of phase shift in a vertical amplifier by considering its effects on a nonsinusoidal signal of the kind shown in Fig. 32-40*a*. Although you will not often deal with a signal that has the shape shown, it is a good shape for illustrating our point. You *will* deal with signals (square-wave, sawtooth, etc.) on which the effect of phase shift is basically similar, although more complicated.

The nonsinusoidal signal shown in Fig. 32-40*a*, for instance, is composed of a fundamental and a third harmonic (Fig. 32-40*b*). This can be proved by making what is known as a *waveform addition*. Such an addition requires adding the amplitudes of the two waves at many points throughout the cycle. If the amplitude of one wave, for instance, is +1 volt at some instant, and the amplitude of the other one is +0.5 volts at that same instant, the net amplitude is 1.5 volts; if one wave is +2 volts at another instant, and the amplitude of the second wave is -1 volt that instant, the net amplitude is +1 volt. When such an addition of the waveforms in *b* is made, the resultant waveform will resemble the one shown in *a*.

To obtain an enlarged but faithful copy of input waveform *a* at the output of the vertical amplifier, the relative amplitudes of the two waveforms comprising it must remain unchanged. If the amplitude of one wave is twice as high as the other one, it must remain twice as high at the output of the amplifier. The amplifier must have a uniform frequency response over its bandpass, for this condition to be met.

Another condition must be met, if the input waveform is to be reproduced faithfully. Nonuniform phase shift must not be introduced by the amplifier. If such a phase shift is introduced, the phase relationship of the 3rd harmonic to the fundamental will be

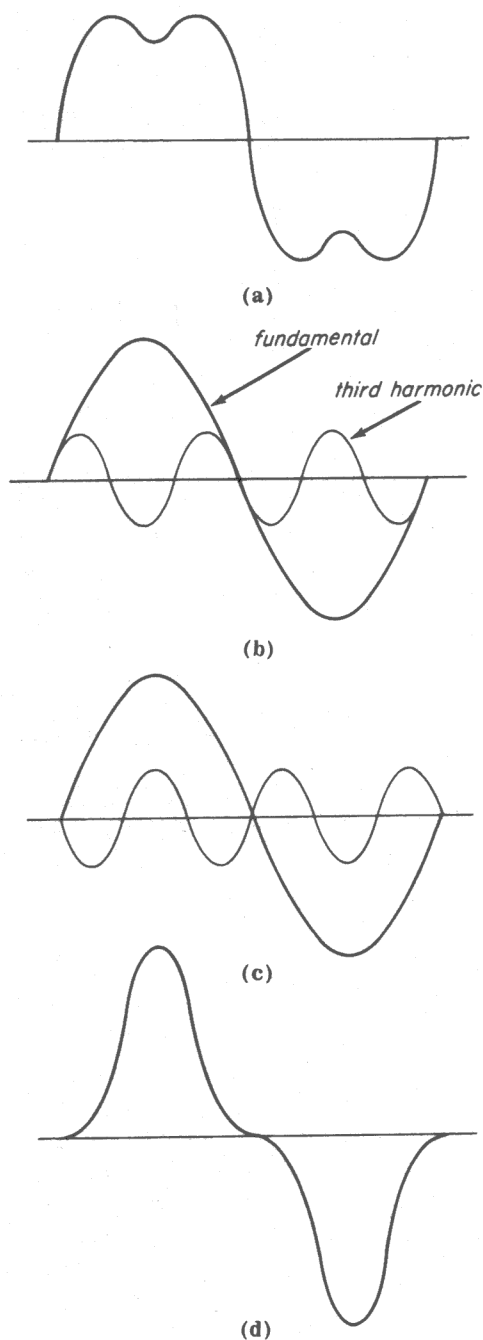


Fig. 32-40

changed. Figure 32-40 illustrates such a change. In *b*, the first half cycle of the 3rd harmonic is positive-going; in *c*, the first half cycle of the 3rd harmonic is negative-going. A phase change of 180 degrees has taken place.

The waveform addition of the two phase-shifted signals will not produce the original waveform shown in *a*; instead, the waveform shown in *d* will be produced. The distortion is the result of nonuniform phase shift.

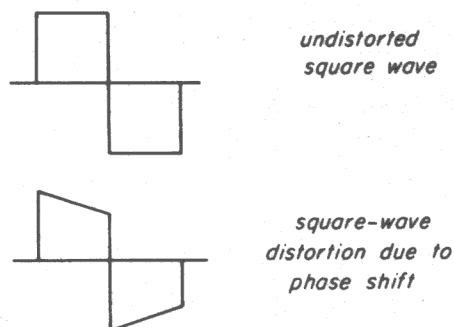


Fig. 32-41

The effect of phase shift on a square wave is illustrated in Fig. 32-41. The change in the phase relations of the many sine-wave signals making up the square wave are responsible for the change in its shape.

Although phase shift cannot readily be eliminated, the effects of phase shift are not objectionable if the phase shift is made *uniform*. In other words, if the different signals in a nonsinusoidal wave are delayed or advanced equal amounts with respect to the timing of their cycles, no distortion will result. The starting times of the two signal cycles in Fig. 32-42*a*, for instance, will be displaced on equal distances toward the left or right when they undergo the same amount of phase shift (Fig. 32-42*b*), leaving their sum unaffected and the shape of the resultant waveform unchanged.

In the vertical amplifier, uniform phase shift is achieved by means of special compensating units. High-frequency compensation

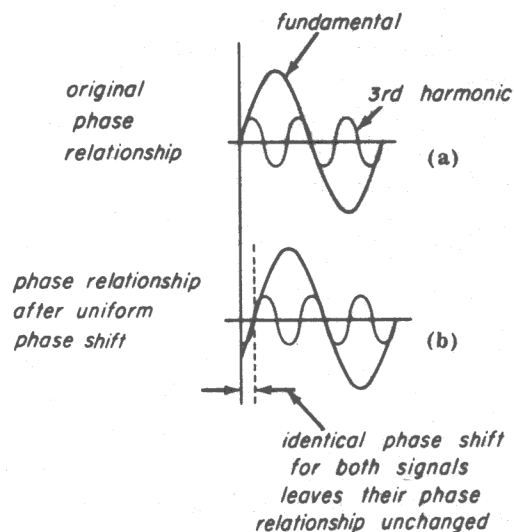


Fig. 32-42

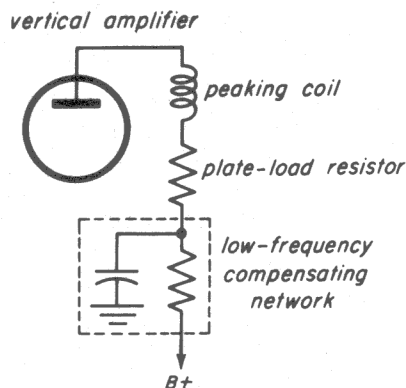


Fig. 32-43

units, called *peaking coils* (Fig. 32-43) make phase shift uniform for high signal frequencies; a network made up of a resistor and capacitor, connected as shown in Fig. 32-43, makes low frequency phase shift uniform. The two components comprise what is known as a *low-frequency compensating network*. In addition to improving the phase response of the vertical amplifier, the compensating network improves its frequency range.

Decibel Ratings and Amplifier Frequency Response. We pointed out earlier in this lesson that the response of an amplifier tends to fall off at the upper and lower limits of its bandpass. The loss in gain that takes place is often expressed in units called *decibels*. The rating in decibels is the ratio of the voltage output of the amplifier at a reference frequency of 1 kc to the voltage output of the amplifier at the maximum or minimum frequency in the bandpass of the amplifier.

The oscilloscope manufacturer may, for instance, say that the vertical amplifier response is 3 db down at 4 mc. This means that the output of the vertical amplifier is 3 db lower than it is at 1 kc. Similarly, if the manufacturer says that the response is 1 db down at 30 cps, he means that the output of the amplifier is 1 db less than it is at 1 kc.

Which brings up the problem of how much of a loss 1 db is. Table A relates db losses to percentage losses and relative amplifier gain. If the gain is 0 db down at some frequency, there is 0 percent loss at that frequency and 100 percent gain. If the gain is

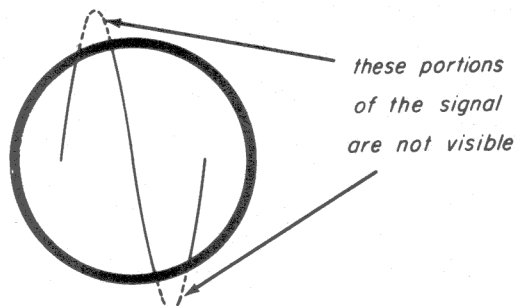


Fig. 32-44

1 db down, the loss in amplification is 10 percent and the gain is 90 percent, etc.

Such information helps you determine which vertical input signals your oscilloscope will reproduce accurately, which ones it will reproduce with some error, and which signals it will not reproduce at all.

Vertical Amplifier Attenuator. When signals of large amplitude are applied to the input of the oscilloscope, some means of attenuating them—i.e., reducing their size—is necessary. Otherwise, the signals will produce vertical deflection that exceeds the limits of the screen; the upper and lower portions of the waveforms will not be visible (Fig. 32-44).

In some oscilloscopes, the amplitude of the vertical signal is controlled by a potentiometer called the *gain* or *vertical gain control*. This control, used at the grid of the first vertical amplifier, controls the amount of signal that is ultimately applied to the vertical deflection plates (Fig. 32-45). The operation of this control is similar to that of a volume control in a radio receiver; it permits a variable amount of signal voltage to be fed to the amplifier.

In other oscilloscopes, an *attenuator switch* as well as a vertical gain control are

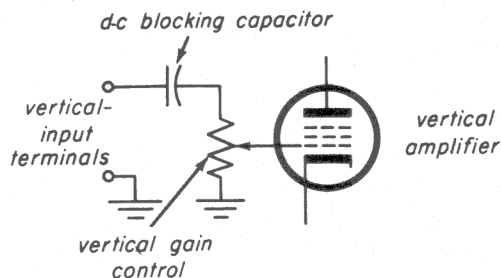


Fig. 32-45

TABLE A - DECIBELS		
Decibels Down	Loss	Relative Gain
0	0%	100%
1	10%	90%
2	20%	80%
3	30%	70%
6	50%	50%
12	75%	25%

employed. Changing the position of the switch varies the signal input to the amplifier. The switch is connected at the vertical input of the oscilloscope, as shown in Fig. 32-46. The vertical gain control, in scopes using both an attenuator switch and vertical gain control, is connected to the input of an amplifier stage following the first one.

The attenuator switch is a voltage divider. It works like a range switch in a voltmeter. Different percentages of the input voltage are made available by changing the switch setting. At the first position $\times 1$ (Fig. 32-46), the entire input voltage is applied to the grid of the 1st vertical amplifier V_1 . At the second position $\times 10$, 1/10 of the input voltage is applied to V_1 . At the third position $\times 100$, 1/100 of the input voltage is applied to V_1 . In some oscilloscopes, an additional setting permits 1/1000 of the input voltage to be applied to V_1 .

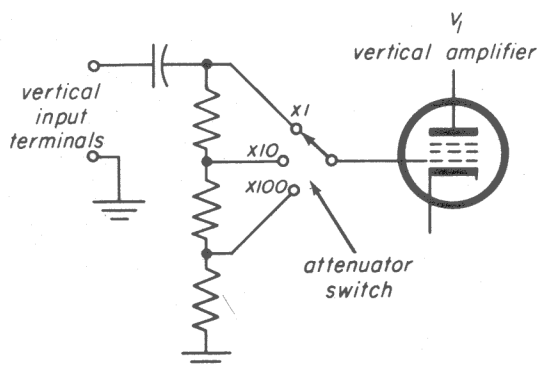


Fig. 32-46

In the oscilloscope shown in the Appendix, the vertical attenuator switch is labeled V RANGE. The vertical gain control is labeled V CAL. The screen of the tube is calibrated in such a way that the voltage of the signal can be read. When the signal is attenuated, the amplitude of the signal appearing on the oscilloscope screen must be multiplied by the attenuation factor to correct the reading obtained. If the signal has been reduced to 1/10 of its value by the attenuator switch, the reading obtained must be multiplied by 10; if the input signal has been reduced to 1/100 of its value, the signal amplitude seen on the screen must be multiplied by 100, etc.

Input Impedance. The input impedance of an amplifier is the impedance or opposition an applied signal will meet when it is connected to the input of the amplifier. The input impedance of the first vertical stage has an important effect on oscilloscope operation, since the signal to be measured is generally connected to the input of this stage.

The a-c input signal is generally applied to the grid of the 1st vertical amplifier through a capacitor (used to block d-c voltage) and a resistor, as illustrated in Fig. 32-47a. In some oscilloscopes, a switch permits the capacitor to be shorted out, so that d-c voltages may be applied and measured. Servicemen do not usually measure d-c voltages with an oscilloscope.

In the representative input circuit shown in Fig. 32-47a, the impedance encountered by the applied a-c signal looks, at first

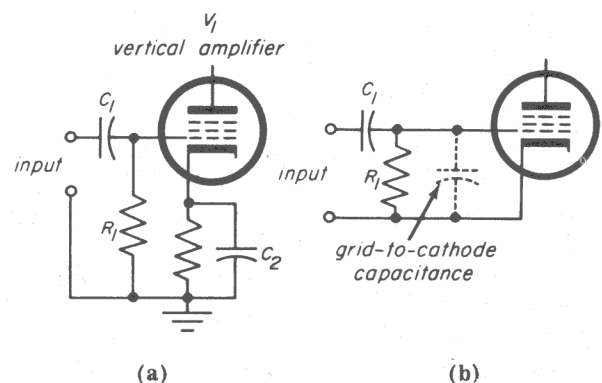


Fig. 32-47

glance, as though it is made up of the sum of the reactance of C_1 and the resistance of R_1 . Matters are not as simple as this, however. There is a capacitance between the grid and cathode electrodes of V_1 (Fig. 32-47b). This capacitance, in combination with the capacitance present between grid and cathode due to wiring and component placement, shunts the resistance across which the applied signal is developed, and thus reduces the input impedance. The higher the frequency of the applied signal, the smaller will be the reactance of C_1 , and the less will be the net impedance present between the grid of V_1 and ground.

The input signal voltage divides across the reactance of C_1 and the impedance between grid V_1 and cathode of V_1 . If the grid-to-cathode impedance changes, the signal input to V_1 will change likewise. Since such impedance changes vary with frequency, the frequency response of the stage will be impaired. But the input impedance of the oscilloscope should be constant over the frequency range of applied signals. Special compensation circuits are used in better-grade oscilloscopes to provide such a characteristic.

The input impedance of the oscilloscope should be *high*, compared to the impedance of the circuit to be checked. Let's consider why this is desirable.

When the oscilloscope is connected to a circuit (Fig. 32-48), current is drawn from the circuit and flows through the input of the oscilloscope. If this current flow is appreciable, the characteristics of the circuit under test will be substantially altered. The higher the input impedance of the oscilloscope compared with the impedance of the circuit under test, the *less* will be the current drawn by the oscilloscope. We say, in such a case, that the *loading effect* of the oscilloscope on the circuit to be checked is small.

Capacitance is also present across the vertical input terminals of the oscilloscope. This capacitance is called the *input capacitance*. It is made up of the sum of all the capacitances in the input circuit, and includes the capacitances between wires, wires and chassis, capacitors and chassis, etc. The capacitance present between oscil-

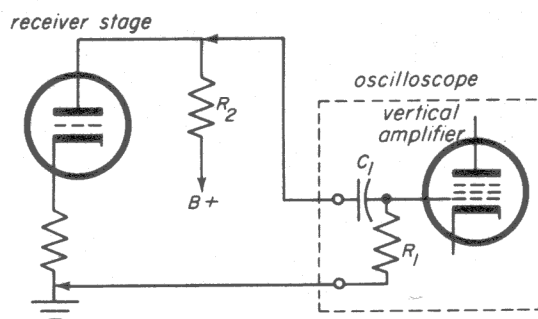


Fig. 32-48

loscope leads adds to the input capacitance. Such capacitance shunts the circuit to be tested, and may cause its operation to be substantially altered, if the reactance introduced in parallel with the test circuit is relatively low (Fig. 32-49). The larger the capacitance of C_2 , the smaller is its reactance compared with the resistance of R_2 , and the greater the shunting or loading effect of C_2 on R_2 .

Low-Capacitance Oscilloscope Probe.

When the circuit to be tested has a high impedance—that is, an impedance as high, or higher, than the input impedance of the oscilloscope—a normal connection of the oscilloscope vertical input to the circuit through the long oscilloscope cable used for this purpose, becomes undesirable. The oscilloscope input capacitance will load down (cause appreciable current to be drawn) the receiver circuit, producing a change in the characteristics of the receiver circuit. Incorrect waveforms will be seen on the screen of the oscilloscope, unless a special unit called a *low-capacitance probe* is employed.

A simple low-capacitance probe is shown schematically in Fig. 32-50. The low capacitance probe causes a smaller amount of

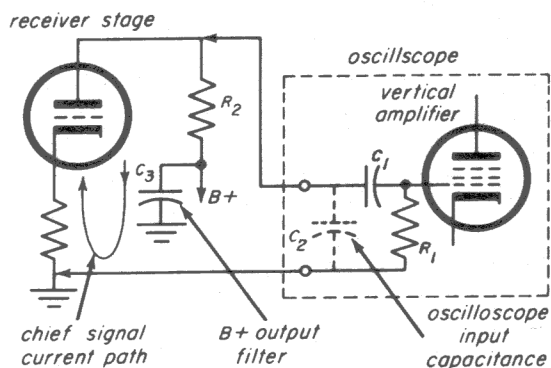


Fig. 32-49

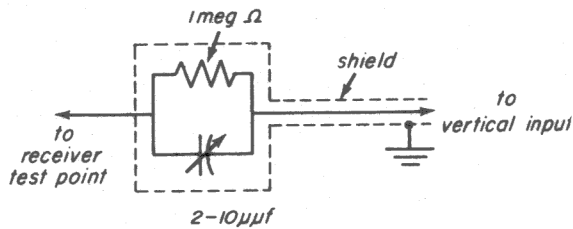


Fig. 32-50

shunt capacitance to be introduced across the circuit to be tested; the probe also increases the effective impedance of the oscilloscope, as seen by the circuit to be tested.

The reason for this is illustrated in Fig. 32-51. A circuit with an input resistance of 1 megohm is shown in *a*. If you add a resistor of 10 megohms in series with the 1-megohm resistor, the input resistance becomes 11 megohms (as in *b*). If a capacitor whose reactance is 10 megohms at some specified frequency is added in series with R_1 , the input impedance is increased to approximately 11 megohms at that frequency (as in *c*). If the resistor and capacitor are added in parallel, the input impedance is increased to approximately 6 megohms at the reference frequency just referred to (as in *d*). Thus addition of resistance and capacitance to the oscilloscope input via a low-capacitance probe has the effect of increasing the input impedance.

There is a good reason for using a resistor and a capacitor instead of a resistor alone. A voltage division takes place across the resistor and the input capacitance of the oscilloscope (Fig. 32-52*a*). The greater the amount of applied signal voltage used up across

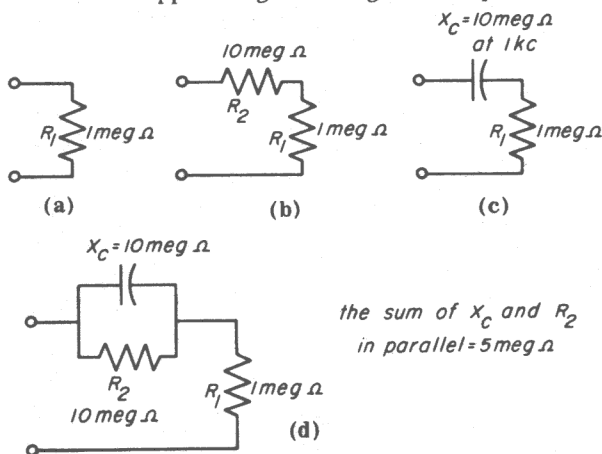


Fig. 32-51

the resistor, the less the signal voltage developed across the input capacitance of the oscilloscope, and the smaller the signal applied to the input of the vertical amplifier.

As the frequency of the applied signal goes up, the reactance of C_2 goes down, causing

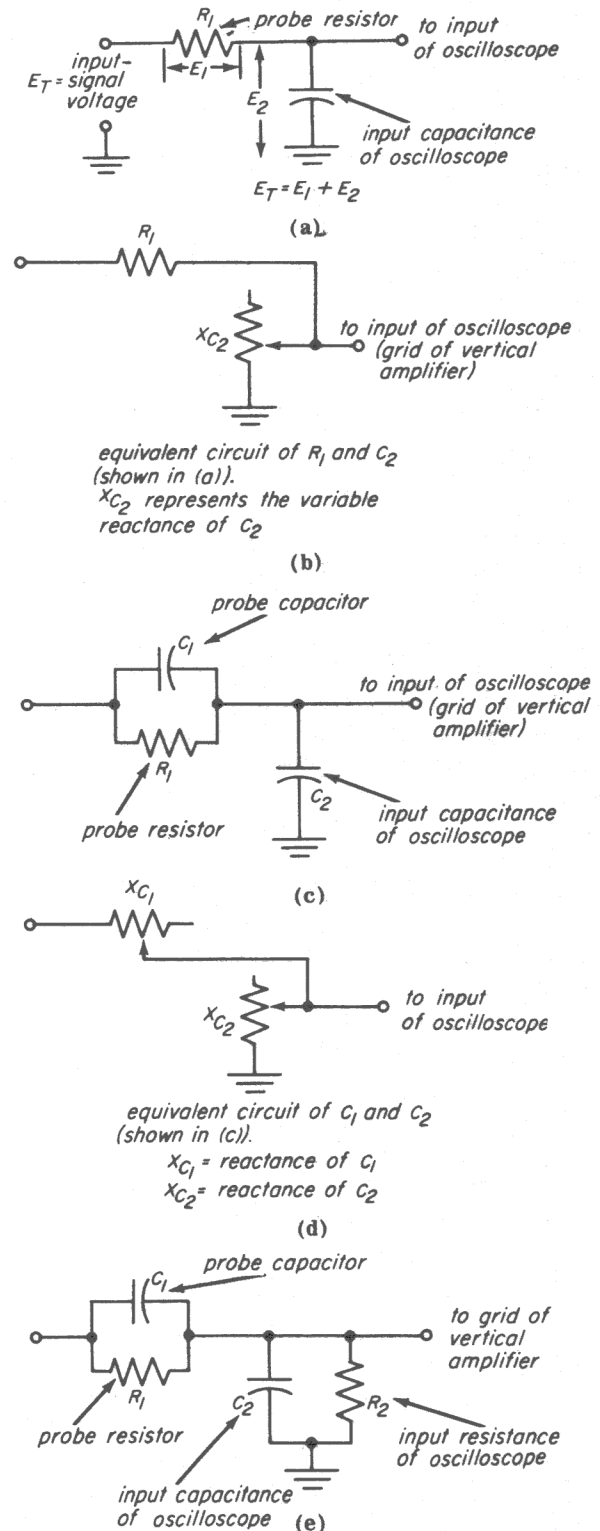


Fig. 32-52

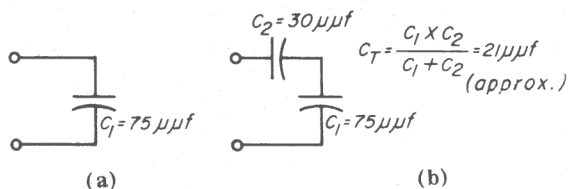


Fig. 32-53

the percentage of applied signal developed across C_2 to decrease (Fig. 32-52b). This is, of course, undesirable, since it causes the frequency response of the vertical amplifier to become nonuniform.

When a capacitor (C_1) is placed in parallel with R_1 (Figs. 32-52c,d), the decreasing reactance of the capacitor as the frequency of the applied signal goes up will tend to cause the signal voltage used up across C_1 to get smaller (just as the decreasing reactance of C_2 tends to cause the signal voltage used up across it to become smaller). When C_1 is adjusted to the proper value of capacitance (Fig. 32-52e), the impedance present across C_1 (in parallel with R_1) and C_2 (in parallel with R_2) will both decrease proportionately as the frequency of the applied signal goes up, with the result that the voltage division across the probe and the input of the oscilloscope will remain constant for all frequencies in the bandpass of the oscilloscope.

The reason that the effective input capacitance of the oscilloscope is reduced through the use of a low capacitance probe is illustrated in Fig. 32-53. Suppose the input capacitance is 75 $\mu\mu\text{f}$ as shown in a. If we add a capacitor of 30 $\mu\mu\text{f}$ in series with the 75- $\mu\mu\text{f}$ capacitor (b), the sum of the capacitors in series is about 21 $\mu\mu\text{f}$. The effective input capacitance is thus considerably reduced. The capacitor in the probe reduces the effective oscilloscope input capacitance—that is, the capacitance presented to the circuit under test—in a similar fashion.

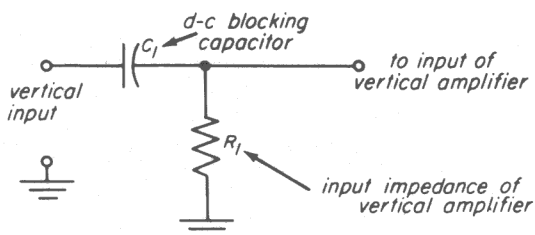


Fig. 32-54

A low-capacitance probe decreases the sensitivity of the oscilloscope vertical amplifier considerably (since a considerable percentage of the applied signal is used up across the impedance of the probe); however, the frequency response of the oscilloscope is unchanged by the probe.

Frequency Compensation in the Vertical Input Circuit. When a vertical gain control is employed at the vertical input of the oscilloscope and its resistance is made high enough to provide the desired high input impedance, the input circuit becomes more *frequency sensitive*; that is, the oscilloscope becomes less uniform in its frequency response.

To understand this better, let's analyze conditions in the input circuit. We pointed out earlier that the applied signal divides across the reactance of the d-c blocking capacitor (C_1 in Fig. 32-54) and the input impedance (represented by R_1). The smaller the input impedance, the smaller the percentage of input signal that will appear across R_1 , in comparison with the percentage of signal that is used up across C_1 .

Let's analyze conditions in the input circuit (Fig. 32-55a) when both high-resistance gain control and a low-resistance gain control are used.

Fig. 32-55b and c show conditions when a high-resistance gain control is used. Signals of two frequencies—1 kc and 1 mc—are successively applied to the input of the oscilloscope, and the gain control is set to a high and low setting during the application of each frequency.

Sketches Figure 32-55d and e illustrate the equivalent circuits present when a low-resistance gain control is employed. Signals of two frequencies—1 kc and 1 mc—are successively applied to the input of the oscilloscope, and the gain control is set to a high and low setting during the application of each frequency.

The frequency response of the gain controls is compared in Fig. 32-55f. A response that decreases linearly between 1 kc and 1

mc is assumed. The response of the low-resistance gain control, as you can see, approaches the ideal one more closely than the response of the high-resistance control. But the use of a low-resistance control at the input is undesirable because the control will load down the receiver circuit

across which the oscilloscope vertical input is applied.

The best method of providing a uniform or nearly uniform response in the vertical input is to use a *compensated vertical attenuator* input circuit.

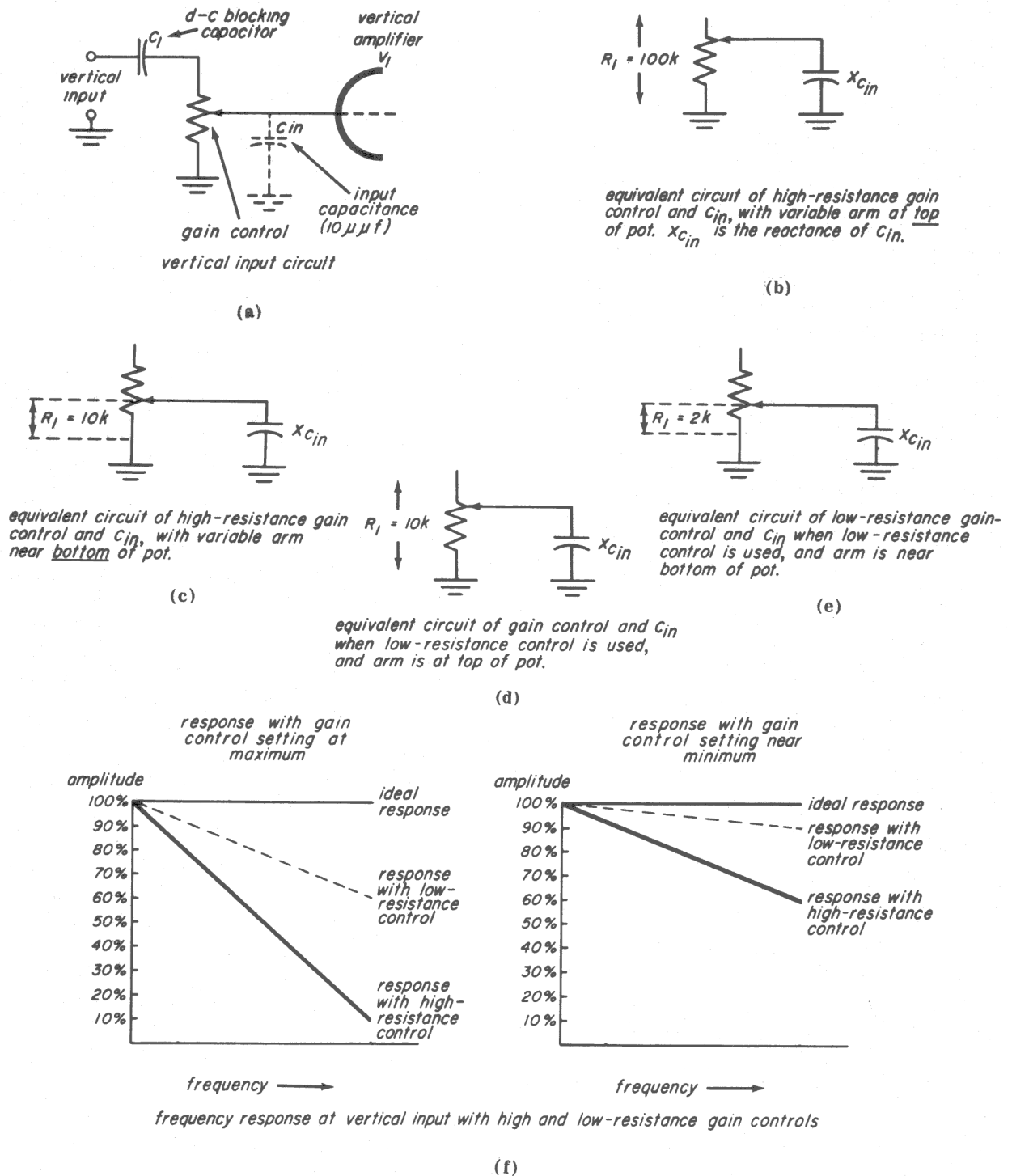


Fig. 32-55

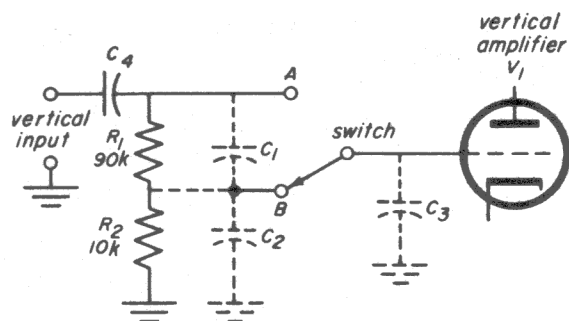


Fig. 32-56

To understand the action of the compensated attenuator, let's first discuss what happens in an uncompensated circuit attenuator. Two sections of such an attenuator are shown in Fig. 32-56. A certain amount of capacitance (due to placement of wires and components, and related circuit conditions) is present across each resistor. This capacitance is labeled C_1 and C_2 in Fig. 32-56. The input capacitance of V_1 is labeled C_3 .

For low and medium frequency signals, the reactance of C_1 , C_2 , and C_3 are so high, that their shunting effect on R_1 and R_2 may be neglected. Such signals will divide across the relatively low reactance of C_4 , and R_1 and R_2 . With the switch at point A, 100 percent of the applied signal will be applied to V_1 (if we consider the reactance of C_4 to be negligible).

With the switch setting at point B, the input to V_1 will depend on the ratio of R_2 to the sum of R_1 to the sum of R_1 and R_2 .

Suppose that the value of R_1 is 90 k-ohms and that the value of R_2 is 10 k-ohms. Therefore, the total voltage drop across R_1 and R_2 is 100 k-ohms. The voltage drop across R_1 is 90 percent of this total.

For high frequencies, the shunting effects of C_1 , C_2 , and C_3 will cause varying percentages of the input signal to be fed to V_1 . The higher the frequency, the smaller will be the percentage of input signal applied to V_1 . A nonuniform response at the high frequency end of the band pass results.

With the compensated attenuator shown in Fig. 32-57, a much more uniform response at the high-frequency end of the bandpass is

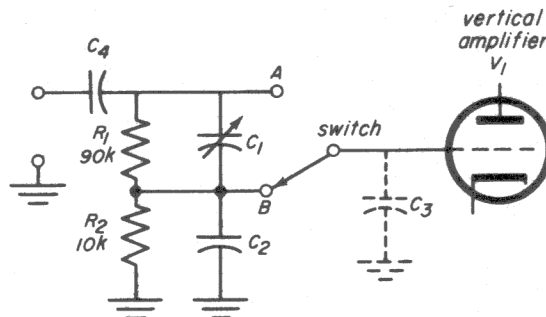


Fig. 32-57

attainable. C_1 is a variable capacitor connected across R_1 ; C_2 is a fixed capacitor connected across R_2 . C_3 is the grid-to-cathode capacitance of V_1 . The values assigned to C_1 and C_2 include the stray capacitance present across R_1 and R_2 . In other words, if C_2 is actually a 10 μmf capacitor, and the stray capacitance across R_2 is 2 μmf , C_2 is considered to have a capacitance of 12 μmf .

For low and medium signal frequencies, R_1 and R_2 act as a voltage divider, in the same manner as in the uncompensated attenuator previously considered. For high frequencies, C_1 , C_2 , and C_3 enter into the division of voltage, as we saw earlier.

The trouble with the uncompensated attenuator is that the reactances of the capacitances present across R_1 and R_2 produce a different voltage division for the applied signal than the resistors do. If these capacitances can be made to produce the same voltage division as the resistors, the problem of frequency discrimination in the input circuit is solved. Such a condition is achieved by choosing suitable values for C_1 and C_2 . Let's illustrate what we mean:

At switch setting B, the ratio of R_2 to $R_1 + R_2$ is 1:10; therefore, 10 percent of the applied signal voltage will be fed to V_1 if the capacitors across the resistors do not change this attenuation ratio. The capacitors won't change the ratio if the same 1:10 proportion exists between the reactance present across R_2 , and the total reactance across R_1 and R_2 .

Using the proper values for C_1 and C_2 provides the desired reactance ratio. When the ratio is correct for one frequency, it

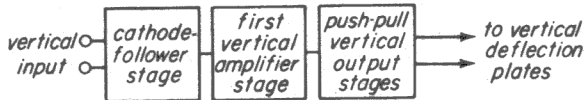


Fig. 32-58

will stay correct for a wide range of frequencies. C_1 is made variable, to permit compensating adjustments to be made when the circuit capacitance changes for some reason. Attenuators with more steps (switch settings) than the one shown in Fig. 32-57 are generally used in oscilloscopes; the action is, however, the same as in the case just described.

Block Diagram of Representative Vertical Amplifier. A block diagram of a representative vertical amplifier section used in a better-grade oscilloscope is shown in Fig. 32-58. The first stage is a *cathode follower*. Cathode follower is the name given to a circuit whose input impedance is very high, and whose output impedance is low (Fig. 32-59). Such a circuit provides no gain, but offers great advantages when used as the first stage of the vertical amplifier section.

We know by now why it is desirable to have a high impedance at the input of the vertical amplifier. The desirability of a low output impedance is that the shunting effect of the output circuit capacitance is reduced, making a better frequency response more easily obtainable.

The output of the cathode follower is taken off at the cathode (not the plate). A low-impedance vertical gain control may be readily connected in parallel with the cathode circuit of the cathode follower. The advantage

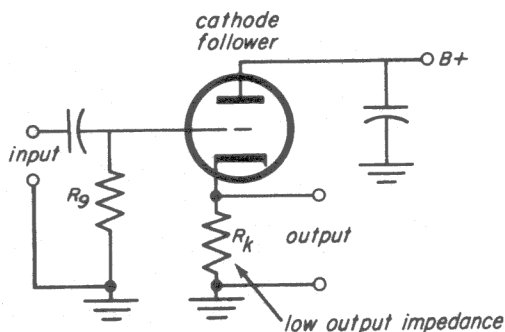


Fig. 32-59

of a low-impedance vertical gain control, you will remember, is that the shunting effect of the circuit capacitance present across the control is relatively small.

Push-pull deflection is used in the vertical (as well as in the horizontal) stages of the better type oscilloscope. This means that one deflection plate repels the beam in the same direction, and with the same force, that the opposite plate attracts it. Oppositely phased voltages are applied to the deflection plates to provide push-pull deflection. These voltages come from push-pull amplifier stages.

32-5. HOW THE OSCILLOSCOPE MEASURES A-C VOLTAGE

In order to measure the amplitude of an a-c signal that is applied to the vertical deflection plates, you must compare the signal with another signal of known amplitude. A signal that may be used for this purpose is derived from the 6.3 volt filament winding of the power transformer. The 6.3-volt value is the rms value. The peak-to-peak value of the voltage is actually 2.8×6.3 , or approximately 18 volts. When the 18-volt test signal is applied to the vertical input of the oscilloscope, it will be seen on the ruled celluloid mask that covers the CRT screen (see Fig. 32-60). This transparent mask is sometimes

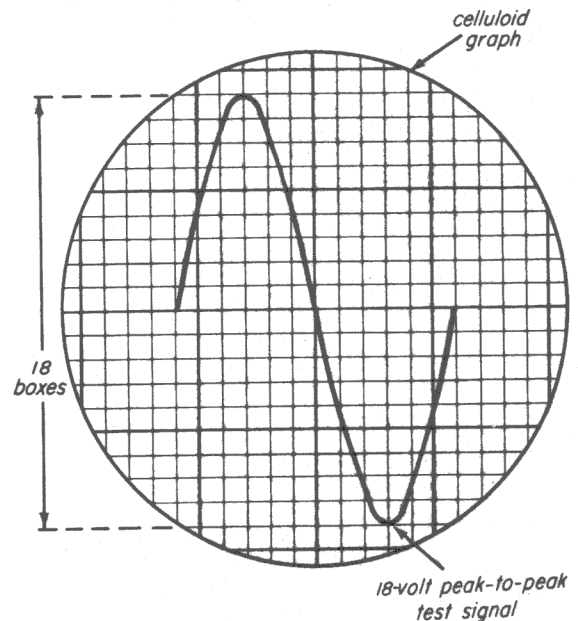


Fig. 32-60

called a *celluloid graph*. The graph is ruled into small squares.

The test signal, which can be applied to the screen by means of a control on the front panel, can be made to cover a varying number of squares in the vertical (or horizontal) direction, by means of the vertical gain control. If the vertical gain control is adjusted so that the 18-volt test signal is made 18 squares high, each square will have a value of 1 volt. When a value is assigned to the squares on the screen, the scope is said to be *calibrated*.

After the oscilloscope has been calibrated, the test signal is removed from the vertical input terminals and the a-c signal to be measured is connected to these terminals. If the signal covers 18 squares vertically, its amplitude is 18 volts peak-to-peak; if it covers 36 squares, its amplitude is 36 volts, etc.

When large a-c signals are to be measured, the test signal used to calibrate the scope must be comparably large; otherwise the voltage to be measured will be deflected off screen. The condition is similar to a voltmeter pointer swinging off scale when a large voltage is measured, and the voltmeter is set to a low-voltage range.

The subject of a-c voltage measurement will be discussed in greater detail in a later lesson dealing with how the oscilloscope is used. In that lesson, you will learn more about the calibration method just described as well as more precise methods of calibration.

The Horizontal Sweep Amplifier. The sawtooth output of the time-base generator is coupled to the input of the horizontal sweep amplifier (also known as the *sweep amplifier* or the *time-base amplifier*). The amplifier is not only used to amplify the sawtooth signal output of the time-base generator; it also isolates the time-base generator from the horizontal deflection plates. Such isolation is necessary to prevent one circuit from having undesirable effects on the other.

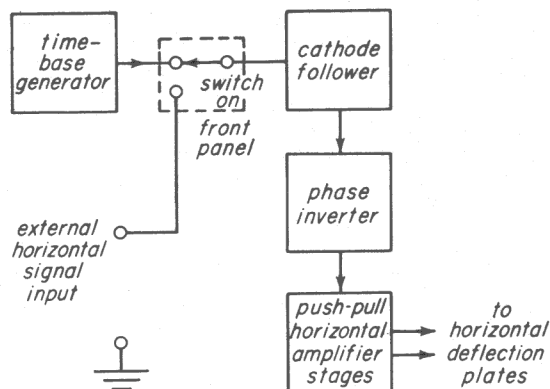


Fig. 32-61

A block diagram of a representative horizontal sweep section used in a better grade of oscilloscope is illustrated in Fig. 32-61. A cathode follower is employed as the *first* stage when the time-base generator is switched out and an external source of sweep signal is used because it permits a higher input impedance to be more readily attained. This is advantageous when external horizontal sweep signals are fed to the horizontal deflection plates, as they are in certain oscilloscope applications; loading of the external source of the sweep signals is minimized.

A phase inverter is used after the cathode follower to feed the final push-pull amplifier stages. The horizontal amplifier section contains a gain control that permits its output to be varied (Fig. 32-62). At one extreme setting of the horizontal gain control, the horizontal amplifier output is reduced to zero, entirely eliminating the horizontal sweep; at the other extreme, maximum horizontal sweep is provided. At in-between settings, intermediate values of horizontal

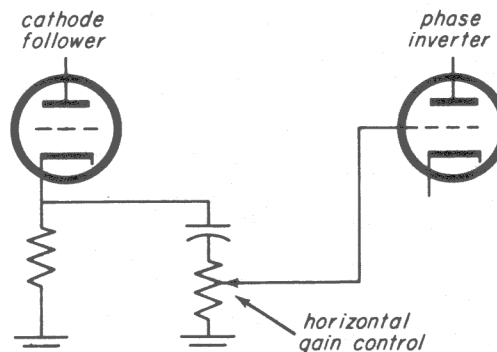


Fig. 32-62

deflection are produced. By manipulating the horizontal gain control, the waveform seen on the oscilloscope may be expanded or compressed in the horizontal direction. Some oscilloscope applications make such horizontal gain control desirable. (For instance, expansion of the waveforms in the horizontal direction makes it easier to check for certain waveform defects.)

Our discussion of frequency and phase requirements in the vertical amplifier section apply in general to the horizontal amplifier as well; the requirements of the horizontal amplifier are, however, much less stringent than the vertical amplifier, since the horizontal section generally has to handle only one type of signal -- a sawtooth -- instead of the many varieties of signal that the vertical amplifier must be capable of passing. The frequency response of the horizontal section does not have to be as great as that of the vertical amplifier because the frequency range of sweep voltages is much less than the frequency range of vertical signals applied to the vertical input of the oscilloscope.

Push-Pull Deflection. In less expensive oscilloscopes, one plate of each pair is grounded; deflection voltage is applied only to the other plate. Such a system is called single-ended deflection (Fig. 32-63a). Figure 32-63b shows *double-ended* deflection, in which deflection voltage is applied to both plates. While single-ended deflection is economical, it has certain disadvantages.

For one thing, a single-ended deflection system subjects the beam to a nonuniform deflection field. The beam is not a point of light; it has a certain radius. The half of the beam that is nearer the active plate will therefore be in a stronger field than the half of the beam that is closer to the inactive plate. At the extremities of the sweep, when the deflection fields are maximum, the difference in field strength for the two halves of the beam will be greatest. Appreciable elongation of the beam in the direction of deflection results (Fig. 32-64).

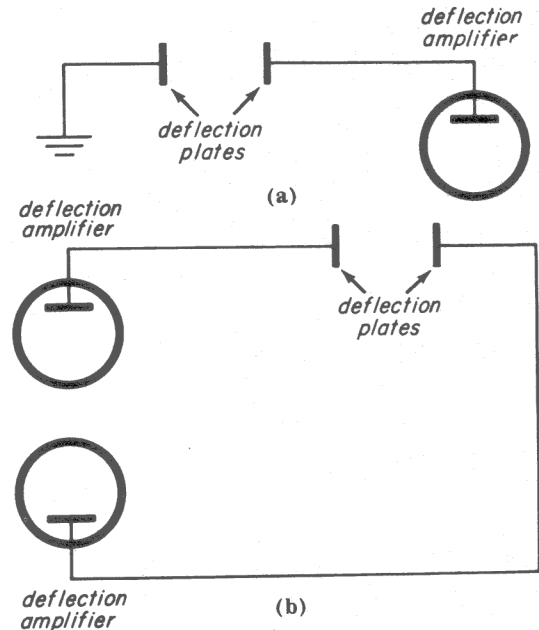


Fig. 32-63

For proper focusing to occur, the beam must be of the correct size. Elongation of the beam introduces defocusing. This defocusing is most noticeable at the extremities of the sweep.

Furthermore, the nonuniformity of the deflection field also introduces nonlinear deflection. The waveform seen on the oscilloscope screen, therefore, tends to be slightly distorted.

When push-pull deflection is used (Fig. 32-63b), the voltage on one plate repels the beam in one direction as much as the voltage on the opposite plate attracts it in the same direction. The deflection field is therefore uniform. Both halves of the beam are simultaneously being acted on by equally

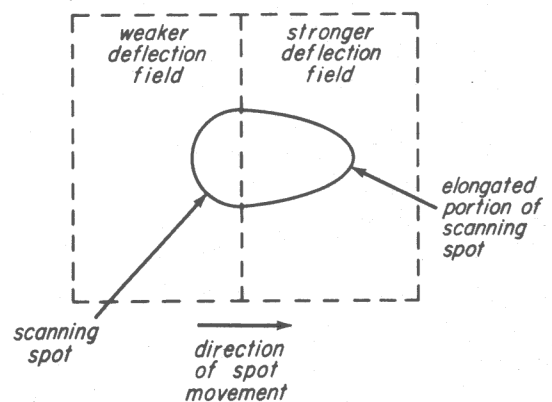


Fig. 32-64

strong fields; elongation of the beam does not occur. Defocusing is avoided, and non-linear deflection is minimized or eliminated.

Vertical and Horizontal Deflection Sensitivity. An important characteristic of an oscilloscope is its *vertical deflection sensitivity*. This may be defined as the voltage at the vertical input which will produce one inch of vertical deflection on the screen. The vertical deflection sensitivity is generally measured at a frequency of 1 kc, with the vertical gain and attenuator controls set to provide maximum deflection.

The smaller the voltage that will produce one inch of deflection, the greater the sensitivity of the scope. An oscilloscope that will produce one inch of deflection with an input voltage of 0.05 volts is more sensitive than an oscilloscope that needs 0.5 volts to produce the same amount of deflection. When very small voltages are to be measured, a high vertical sensitivity is necessary; an oscilloscope whose vertical sensitivity is poor may not reproduce small signals in any measurable amount.

Typical vertical amplifier sensitivities range from 0.01 to 0.4 volt rms per inch.

Of considerably smaller importance is the *horizontal deflection sensitivity*. This may be defined as the voltage needed at the horizontal deflection on the oscilloscope screen. The deflection sensitivity of the horizontal amplifier is generally less than that of the vertical amplifier. Typical horizontal deflection sensitivities range from 0.022 to 0.6 volt rms. Horizontal deflection sensitivity is important in determining how much sweep will be produced when an external of horizontal sweep voltage is connected to the oscilloscope. Oscilloscope applications in which such a connection is needed will be discussed in a later lesson.

Centering Circuits. Various conditions make it necessary to shift the position of the waveform image, reproduced on the

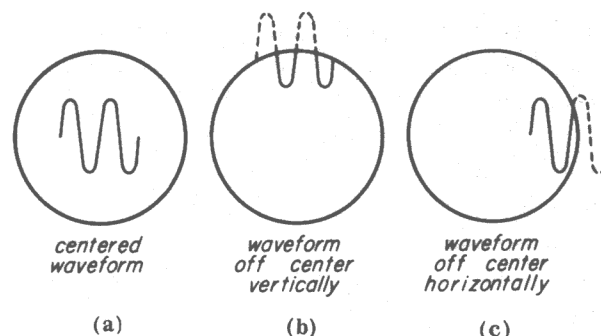


Fig. 32-65

screen in the vertical direction, horizontal direction, or both (Fig. 32-65). The circuits used for this purpose are called *centering circuits*. They are located in the horizontal and vertical amplifier sections of the oscilloscope. The centering circuits employ potentiometers called *centering* or *positioning controls*. Two controls are used: one for horizontal positioning, the other for vertical positioning.

To understand the operation of a centering circuit, let's analyze what happens when beam positioning is correct and when it is incorrect. We can then more readily comprehend the action of the circuits used to change the beam positioning.

Under normal conditions the beam will, when undeflected, strike the center of the screen (refer to Fig. 32-66a). Suppose the horizontal sweep is working, but no vertical signal is being applied to the scope. A horizontal line will be traced out, as indicated in Fig. 32-66f. The different sequence of beam movements that take place during the tracing of the horizontal line are indicated in sketches a through e of Fig. 32-66.

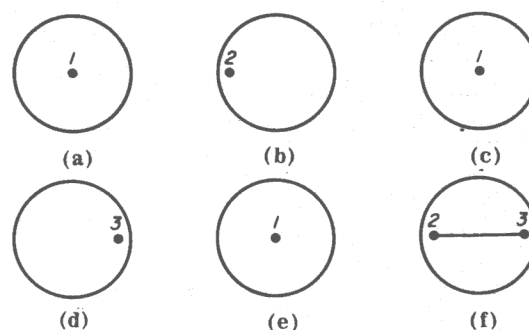


Fig. 32-66

Let's assume we are considering the action just when the retrace is half over, and the beam has been swept from the right hand side of the screen to the center. During the second half of the retrace, the beam moves from point 1 to 2. The trace starts now, and the beam moves from point 2 to 1, then to point 3, which is where the trace ends. The first half of the retrace brings the beam back to point 1, completing one cycle. A horizontal line is seen as the result of these beam movements. The line is properly centered.

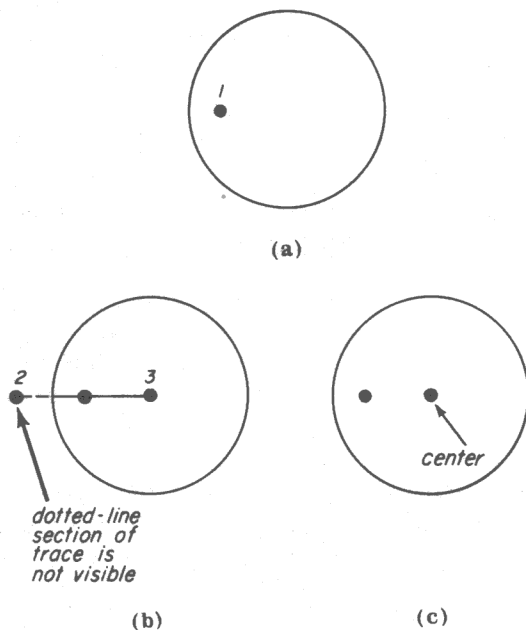


Fig. 32-67

Now let's consider what happens when, with neither horizontal nor vertical deflection voltages applied to the deflection plates, the beam is off center (Fig. 32-67a). When a horizontal deflection voltage is applied, it may be strong enough to cause the beam to trace and retrace between points 2 and 3, as shown in Fig. 32-67b. However, point 2 is not visible on the screen. As a result, the portion of the trace and retrace between the edge of the screen and point 2 cannot be seen. However, if the beam were moved from the off center starting position we have discussed to the center position, as shown in Fig. 32-67c, the same horizontal voltage that caused the trace and retrace to go beyond the screen in Fig. 32-67b would not cause the beam to go off the screen.

The entire trace and retrace would be inside the limits of the screen.

We saw, in an earlier part of this lesson, that a difference in d-c potential between the horizontal deflection plates will cause the beam to be deflected from its center position. The beam will move toward the more positive plate. The distance it moves from center will depend on how much more positive this plate is than the opposite plate. Centering circuits introduce such a difference in the potential between sets of deflection plates.

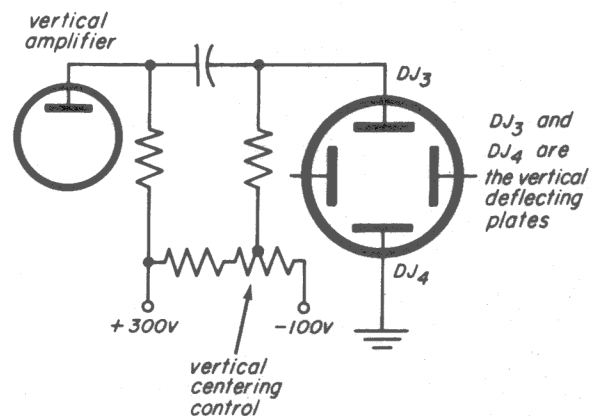


Fig. 32-68

Some centering circuits shift the position of the beam by varying the d-c voltage applied to one of the deflection plates; by making one plate more positive than the other, the starting position of the beam is suitably shifted. The amount of the shift depends on the amount of d-c voltage difference introduced. A system of this kind used for vertical centering is illustrated in Fig. 32-68; a similar circuit is used for horizontal centering.

In oscilloscopes using push-pull deflection circuits, one deflection plate is made more positive at the same time that the other is made more negative; a balanced centering action is obtained in this way, since one plate repels the beam in one direction as much as the other plate attracts it in this direction.

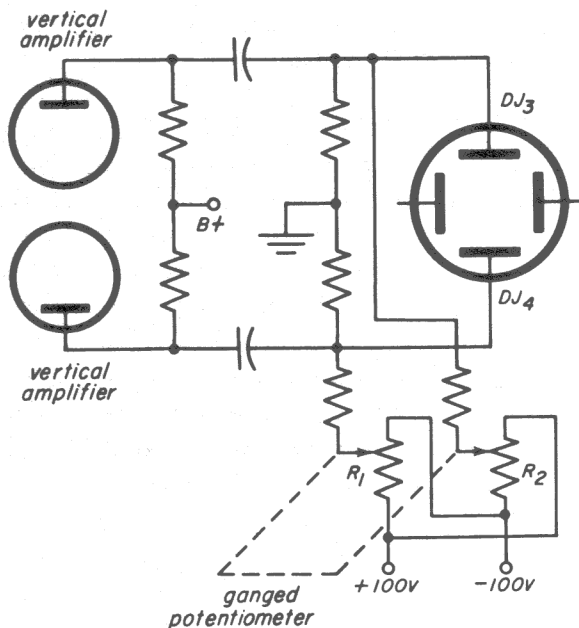


Fig. 32-69

A representative circuit is illustrated in Fig. 32-69. R_1 and R_2 are ganged potentiometers. The variable arms of both move in step. When the R_1 arm moves down, for instance, so does the R_2 arm. The arms move toward opposite voltages, however. When the R_1 arm is moving toward the +100 volt source, the R_2 arm is moving toward the -100 volt source, and vice-versa. The d-c voltages applied to the deflection plates are thus opposite and equal.

In oscilloscopes using push-pull circuits that are direct-coupled to the deflection plates (no coupling capacitors are present in such circuits to improve the low-frequency response) centering is obtained by varying the bias of one of the push-pull amplifiers (V_2 , Fig. 32-70). A change in the d-c bias of V_2 causes a change in the d-c plate current of V_2 , which causes the d-c voltage drop across the V_2 load resistance (R_2) to change, which in turn causes the d-c plate voltage of V_2 to alter; since deflection plate DJ_2 is connected to the V_2 plate, the d-c voltage of the DJ_2 with respect to DJ_1 is altered, causing the horizontal centering of the beam to change.

Keep in mind that changes in the d-c voltage difference between deflection plates has nothing to do with the a-c voltages applied to these plates. The a-c deflection voltages control how far the beam will sweep in either direction (horizontally or vertically); the d-c voltages merely determine the point from which the beam starts its sweep.

32-6. OSCILLOSCOPE POWER SUPPLIES

Two power supplies are used in the oscilloscope. One, a high-voltage power supply (abbreviated *hups*), provides the high d-c potentials needed to accelerate the electrons from the cathode to the fluorescent screen. The other, a low-voltage power supply (abbreviated *lups*) provides the B+ voltages required by the various stages used in the oscilloscope.

High-Voltage Power Supply. In a conventional vacuum-tube circuit, the plate is made positive with respect to cathode in order to cause a flow of electrons from cathode to plate. Instead of saying that the plate is positive with respect to the cathode, we could say that the cathode is negative with respect to the plate.

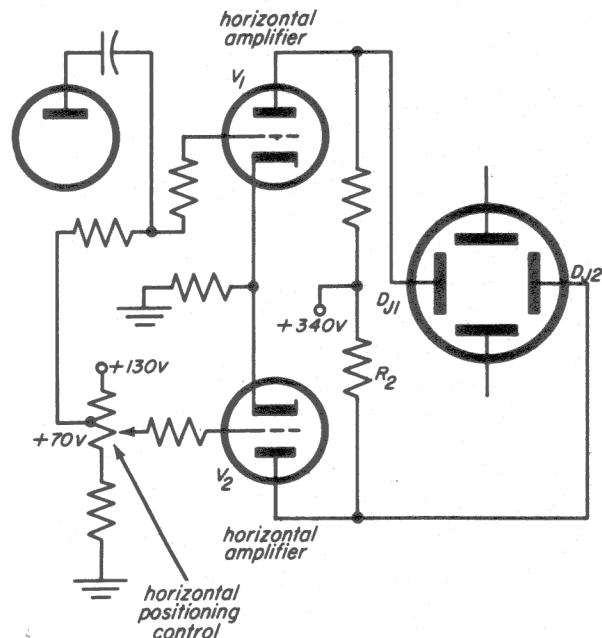


Fig. 32-70

In Fig. 32-71, the plate is grounded. Therefore it is at zero potential with respect to the rest of the circuit. The negative side of a 1,000-volt battery is applied to the cathode. As a result, the cathode is 1,000 volts negative with respect to ground. On the other hand, ground is 1,000 volts positive with respect to the cathode—that is, it is 1,000 volts positive with respect to -1,000 volts. So you see that it is possible for ground, which is at zero potential, to be positive with respect to a negative voltage. This idea is put to good use as a safety measure in oscilloscope circuits.

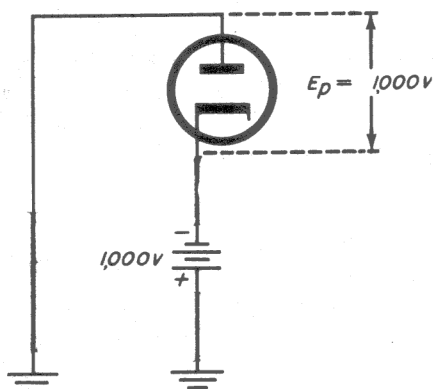


Fig. 32-71

The second anode in the oscilloscope must be at approximately the same potential as the deflection plates, to prevent the development of electrostatic fields between the second anode and the deflection plates. Such fields would defocus the beam. Now, if the second anode were at a high positive potential, the deflection plates would have to be at the same high potential.

A high negative voltage (with respect to ground) is applied to the cathode of the CRT; the second anode is placed at or near ground potential.

Direct connections must be made to the deflection plates for certain tests. Terminals that connect to the plates are generally made accessible at the rear of the oscilloscope. If these terminals were at high-voltage potentials, serious shock hazards would be introduced.

One power transformer is generally common to the low- and high-voltage power supplies (see Fig. 32-72). The line voltage is stepped up by secondary windings L_1 , L_2 , and L_3 . L_2 and L_3 are similar to the secondary windings of a transformer in a conventional low-voltage power supply using a full-wave rectifier. L_1 is used to supply part of the high-voltage input. The a-c voltage built up across L_1 in series with L_2 is fed to the filament-type cathode of V_1 , the high-voltage rectifier. L_2 serves to provide input voltage for both the high- and low-voltage rectifier tubes. This feature makes possible a reduction in the voltage that must be provided by L_3 , the winding feeding the input of the high-voltage rectifier tube. If part of the input voltage to the high-voltage rectifier was *not* provided by L_2 , L_1 would have to provide the entire voltage needed by itself; a greater number of turns would be needed for L_1 , and the heavier insulation required for the transformer windings would increase the cost of the transformer.

In the circuit shown in Fig. 32-72, a voltage of 715 volts a.c. is applied between filament-cathode and ground of V_1 , the high-voltage rectifier; a voltage of 365 volts is applied between each plate and ground of V_2 , the low-voltage rectifier.

The high-voltage rectifier is a half-wave type—it conducts only on that half of the input voltage cycle at which the cathode is made negative with respect to the plate. (When the cathode is made negative with respect to the plate, the effect is the same as if the plate was made positive with respect to the cathode. Resistor R_B , in conjunction with capacitors C_1 and C_2 , serves as a pi-type filter. The filtered d-c current flowing through R_B , and the resistors in series with it (R_1 , R_2 , R_3 and R_4) builds up a negative voltage of 1,000 volts between point X (the output side of the filter resistor) and ground. This voltage (in conjunction with the B+ voltage with which it is in series) provides the potentials needed by the different CRT electrodes. A bleeder network (made up of resistors R_1 , R_2 , R_3 and

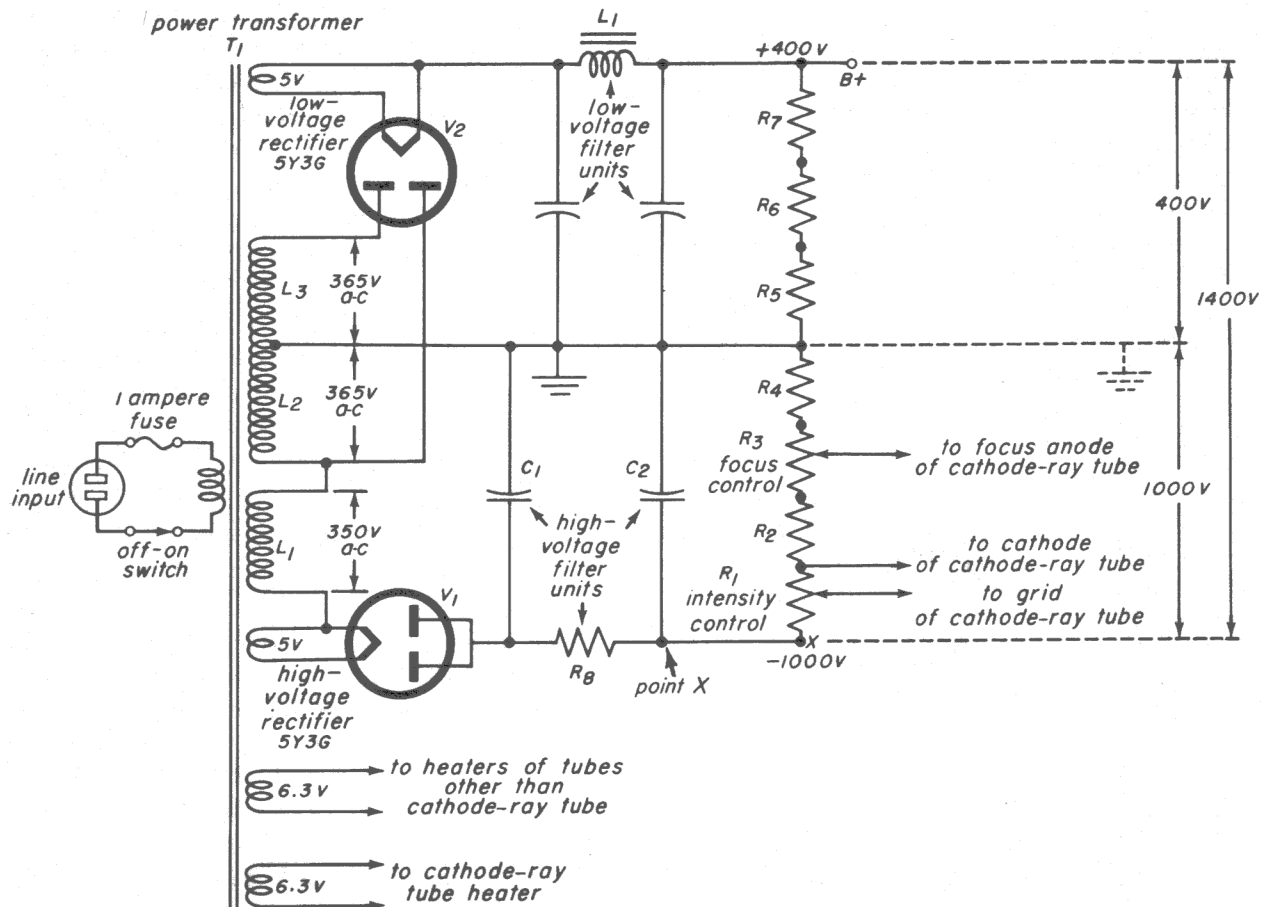


Fig. 32-72

R_4 at the output of the hv supply permits the different levels of d-c voltage required by the CRT electrodes to be tapped off.

The d-c voltage fed to the CRT control grid must be slightly more negative than the voltage applied to the cathode, to bias the tube properly. The grid is therefore attached to a portion of the bleeder that is more negative than the point to which the cathode connects.

The voltage for the focus electrode comes from a point in the bleeder less negative than the cathode. Like the control-grid voltage, the focus anode voltage is regulated by a potentiometer, which permits it to be adjusted to the correct value. A change in focus anode voltage (focus setting) is generally required if the control grid voltage (intensity setting) is altered. This is so because the width of the beam, as well as its first focal point, is varied when the CRT

bias is altered. The beam will not come to focus on the screen unless suitable compensation is made by changing the setting of the focus control.

The d-c output of the low-voltage power supply is connected in series with the d-c voltage output of the high-voltage power supply, in the circuit shown in Fig. 32-72. This is, like the series connection of L_1 and L_2 at the input of the high-voltage supply, a design feature promoting manufacturing economies. The output of the high-voltage power supply need not be as great as it would otherwise have to be, if the output of the low-voltage power supply is connected in series with it. If the high-voltage needed is 1400 volts, and the voltage developed by the low-voltage power supply is 400 volts, the high-voltage power supply delivers only 1,000 volts to satisfy the demands of the circuit; connection of the 1,000-volt and the 400-volt outputs in series

will provide the 1,400 volts needed in this particular case.

The d-c high-voltage needed for oscilloscope operation ranges from approximately 750 volts to as high as 5,000 volts.

The low-voltage power supply is carefully filtered by a filter choke and high-capacitance electrolytic capacitor to keep ripple at the output of the supply very low. If the ripple is appreciable, hum voltages will be fed to the deflection plates, and will cause undesired deflection to take place.

32-7. A COMMERCIAL OSCILLOSCOPE CIRCUIT

Now that we have completed our discussion of the various stages in the oscilloscope, we are in a position to analyze the schematic diagram of a complete oscilloscope. The circuit of a representative commercial oscilloscope is illustrated in Fig. 32-73. Points marked A, B, and C in the various stages connect to similarly-marked points in the power supply.

The vertical input circuit contains a 3-position step attenuator switch. The first vertical stage is connected as a cathode follower. The advantages of using such a circuit as the first stage were discussed earlier in the lesson. The plate V_1 is kept at a-c ground potential by the $8\text{-}\mu\text{f}$ bypass capacitor in order to avoid signal voltage losses across the 47 k-ohm d-c voltage dropping resistor in the plate circuit. The signal output of V_1 is taken off at the cathode via a $10\text{-}\mu\text{f}$ capacitor in series with the vertical gain control. The capacitor is made very large in order to make its reactance to low frequencies small and thus minimize the attenuation of low-frequency vertical signals. For medium- and high-frequency signals, a much smaller capacitor would have been adequate; the reactance of a coupling capacitor and the attenuation it introduces, are appreciable only at low frequencies.

Because V_1 is connected as a cathode follower, it provides no amplification. This function is performed by V_{2A} and V_{2B} . The 47 k-ohm resistor in the plate circuit of both tube sections is used to introduce negative feedback. The plate currents of V_{2A} and V_{2B} both pass through this resistor. Since these currents are 180 degrees out of phase, they buck, but do not completely cancel, each other. The net, or residual plate current is reduced in amplitude, but it contains less distortion, than it would otherwise have had (see Fig. 32-44). Additional negative feedback (cathode degeneration) is provided by leaving the cathode resistors of V_{2a} and V_{2b} unbypassed. The amount of negative feedback needed cannot be provided by using cathode degeneration alone; resistors large enough to provide such feedback would bias V_{2a} and V_{2b} improperly. The plate load resistance of V_{2a} consists of the 4.7 k-ohm and 47 k-ohm resistors in series; the plate load resistance of V_{2b} consists of the 22 k-ohm and 47 k-ohm resistors in series.

V_3 acts as a phase splitter. It provides the 180-degree out-of-phase signals needed to drive the push-pull vertical amplifier stages V_{4a} and V_{4b} .

The plate of V_{2b} is directly-coupled to the grid of V_3 . This connection eliminates the need for a coupling capacitor and grid resistor for V_3 . The 22 k-ohm and 47 k-ohm resistors in the V_{2b} plate circuit comprise the grid resistance of V_3 .

Even though the V_3 grid-to-ground voltage is made positive by the connection just described, the V_3 bias is negative, because the cathode-to-ground voltage of V_3 is more positive than the grid-to-ground voltage. The cathode-to-ground voltage is +55 volts; the grid-to-ground voltage is +50 volts, making the V_3 bias -5 volts.

Some of the vertical signal voltages developed in V_3 is tapped off through the two 470 k-ohm isolating resistors, (one in the cathode circuit, the other in the plate circuit).

and fed to points G_1 and G_2 in the switch circuit associated with the sync control and the external sync terminal. This switch is labeled S_1 in Fig. 32-73. When this dpdt switch is set so that the sync control is connected (through the 0.02- μf capacitors) to G_1 and G_2 , oppositely-phased vertical signal voltages are transferred from V_3 to each end of the sync control.

When the variable arm of the sync potentiometer is moved from the midpoint setting to one extreme, a varying amount of *positive-going* sync voltage will be fed to the input of V_5 , the time-base generator. When the variable arm of the sync potentiometer is moved from the midpoint setting to the other extreme, a varying amount of *negative-going* sync voltage is fed to the input of V_5 .

The reason that the polarity of the sync voltage fed to one end of the sync pot is opposite to that of the voltage fed to the other end is that the voltages come from the plate and cathode circuits, respectively, of V_3 , and are therefore 180 degrees out of phase, or opposite in polarity.

We have just explained the circuit action with S_1 at one setting (internal sync). Now let us complete the description by describing what happens when S_1 is at its other setting. With S_1 set to the external sync position, both sides of the sync control connect (through the 0.02- μf capacitors) to the external sync terminal. This setting is used when an external sync signal is to be applied to the time base generator. The signal voltage developed across each half of the sync potentiometer is the *same* in polarity; no reversal of sync voltage polarity may be made by suitable rotation of the potentiometer.

V_{4A} and V_{4B} comprise the push-pull vertical output stage. The coils in the plate circuits of these tube sections are peaking coils, used to improve the high-frequency response. The 0.5- μf capacitor across the vertical centering potentiometer bypasses signal currents from the vertical centering potentiometer, keeping the voltage across the potentiometer pure d-c, which is what is needed for centering adjustments. If

the potentiometer wasn't bypassed, V_{4a} and V_{4b} would have different plate load impedances at different settings of the potentiometer, and unequal vertical deflection voltages would be developed at the output of the push-pull amplifiers. Non-linear vertical deflection would result.

V_{6a} and V_{5b} form a multivibrator-type time-base generator. The frequency of the generator is varied to a limited extent by a dual-ganged potentiometer, which simultaneously varies the time constants in the grid and plate circuits of V_{5b} . This potentiometer serves as the fine frequency control.

The frequency of the time-base generator is varied in large steps by means of switches S_{3a} and S_{3b} . S_{3a} switches in a different capacitor between the plate of V_{5a} and the grid of V_{5b} at different frequency settings, suitably changing the multivibrator's frequency of operation; at the same time, a different charge-discharge capacitor is switched into the plate circuit of V_{5b} by S_{3b} . This change is necessary to help keep the frequency of operation correct, as well as to provide the same amount of output at different time-base generator frequency settings.

S_2 , a dpdt switch, connects the output of the time-base generator to the input of V_6 , a horizontal phase inverter, at one setting; at its other setting, S_2 connects an external horizontal sweep signal to V_6 , and also disconnects the plates of time-base generator from point A in the B supply, thus making the generator inoperative.

A 60-cps test signal is taken from the hot side of the filament winding labeled X-X in the power supply, and fed to a front panel terminal through a 10 k-ohm resistor. The 10 k-ohm resistor prevents damage to the power transformer if the test signal terminal is accidentally shorted to the oscilloscope case.

V_6 feeds out-of-phase signals of the proper polarity to push-pull tube sections V_{7A} and V_{7B} . A dual ganged potentiometer is used as the horizontal gain control in this

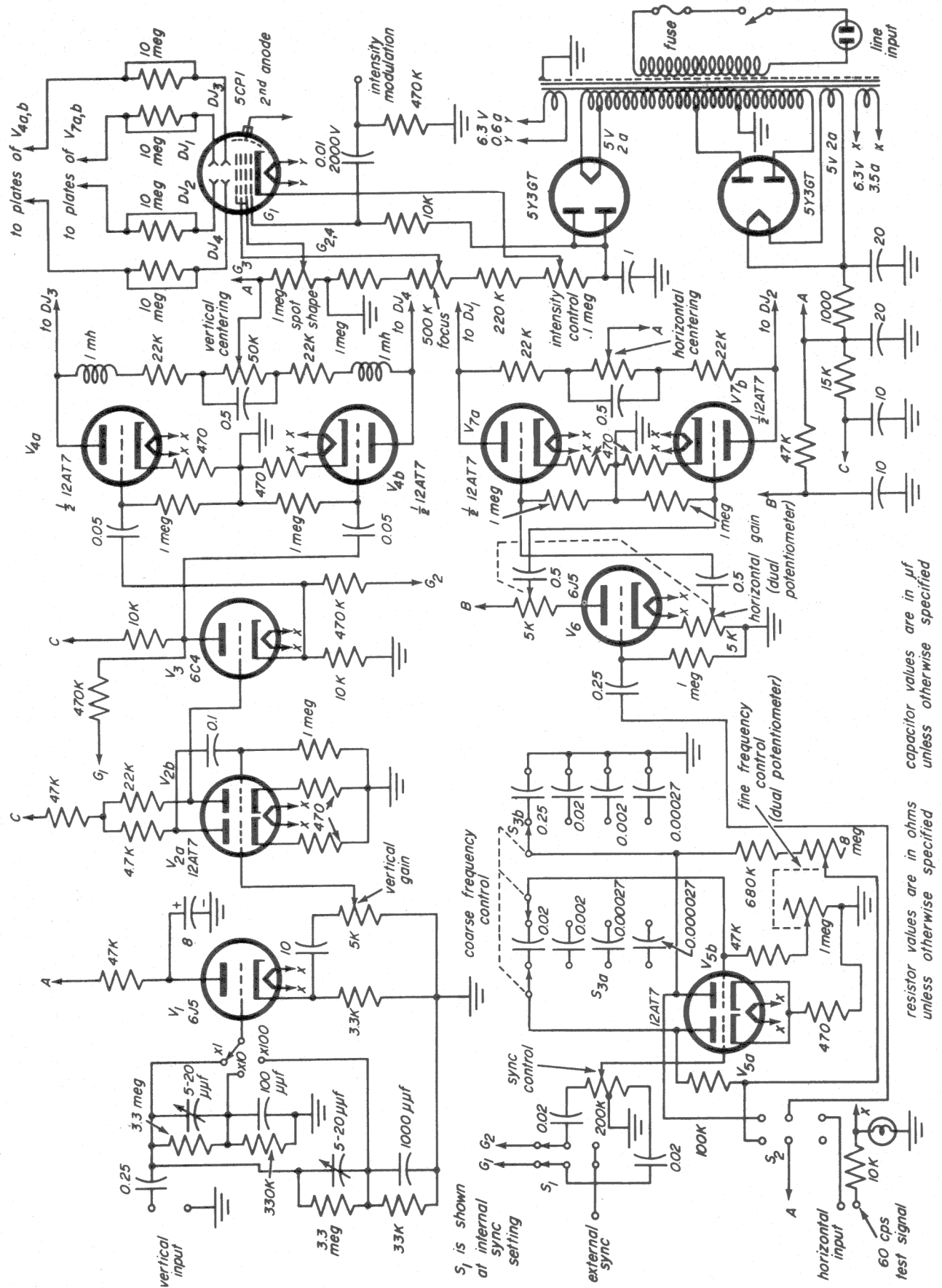


Fig. 32-73

stage. The potentiometer provides equal amounts of signal take-off at the cathode and plate of V_6 at different horizontal gain control settings.

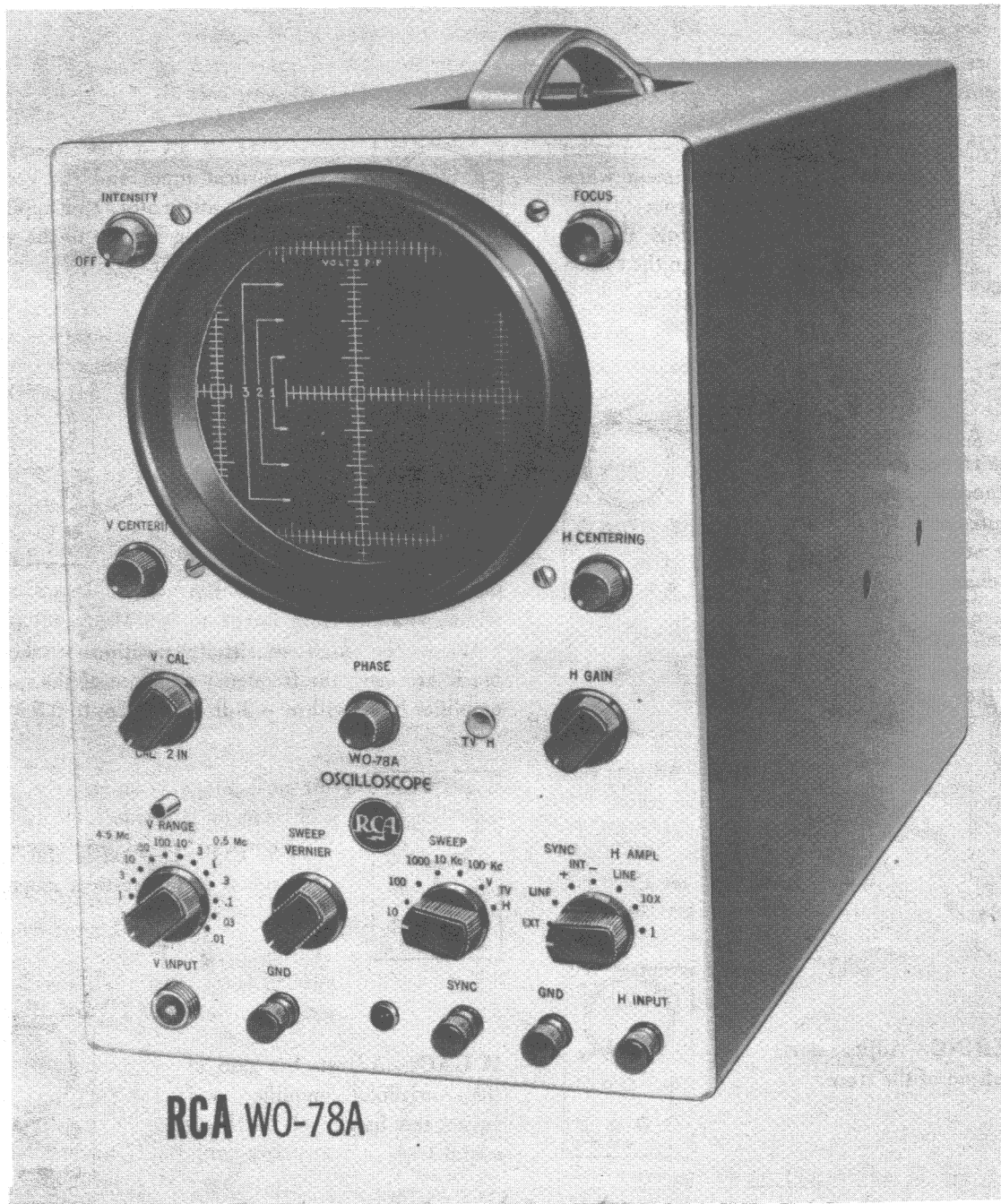
The high- and low-voltage power supplies are similar to the ones we analyzed earlier in the lesson. The power supplies are in series, both at the input and output of the rectifier tubes. B^+ voltage taken off at point A in the low-voltage power supply is fed to the second anode of the 5CP1 cathode-ray tube.

A special control, referred to in the cir-

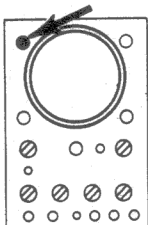
cuit as a spot shape control, is used to improve the uniformity of focusing over the face of the cathode-ray tube. With this control, the scanning spot can be adjusted for optimum roundness.

The 10-megohm resistors in series with the deflection plates of the CRT are useful when signals are applied directly to the deflection plates. The wires across the resistors are removed under such conditions. The resistors prevent the capacitance at the outputs of the deflection output tubes from directly shunting, and thus attenuating, the signal applied to the deflecting plates.

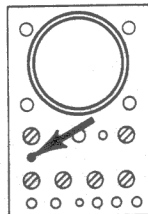




Functions of Controls and Terminals

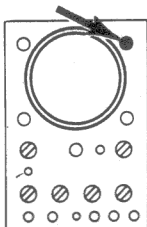


OFF-INTENSITY — Applies power to the instrument when turned clockwise from "OFF" position and controls the intensity of the spot on the screen of the cathode-ray tube.



CAL 2 IN — Disconnects the vertical input and the vertical input attenuator, and applies a calibrating voltage to the vertical amplifier.

FOCUS — Adjusts the sharpness of the trace on the screen of the cathode-ray tube. Normally requires adjustment when the setting of the INTENSITY control is changed.

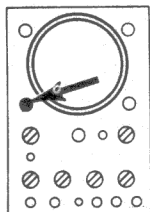
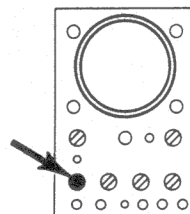


VOLTS P-P/IN (V RANGE)

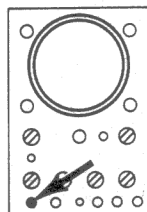
—Controls the degree of vertical-input-voltage attenuation in calibrated steps.

When the wide-band switch positions marked in red are used, the frequency response of the vertical amplifier is flat within -1 db from 3 cps to 4.5 Mc.

When the high-sensitivity positions marked in black are used, the frequency response of the vertical amplifier is flat within -3 db from 3 cps to 0.5 Mc.

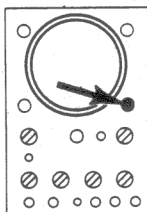


V CENTERING—Adjusts vertical position of the trace.

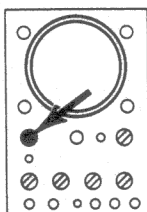
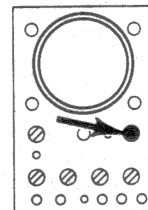


V INPUT — Feeds the input signal to the vertical amplifier.

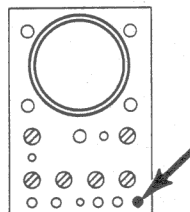
H CENTERING—Adjusts horizontal position of the trace.



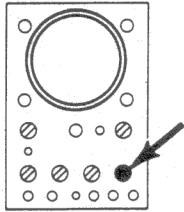
H GAIN—Adjusts the gain of the horizontal amplifier and varies the length of the horizontal trace.



V CAL — Permits continuous adjustment of the vertical-amplifier gain; and is used in conjunction with the CAL 2 IN switch to calibrate the instrument.



H INPUT—An external signal for the horizontal amplifier may be connected between this terminal and the ground terminal; and the SYNC H AMPL control set to either "1" or "10 X".



SYNC H AMPL—Has three functions; selects sync voltages for the sweep oscillator, applies an external horizontal-deflection voltage to the horizontal amplifier, or applies a line-frequency sine wave to the horizontal amplifier.

“SYNC” Function

“Ext”—Feeds the external synchronizing voltage applied at the “SYNC” terminal to the sweep oscillator.

“Line”—Feeds an ac signal from the power supply to the sweep oscillator to sync the oscillator at the power-line frequency.

“Int+”—Selects the synchronizing voltage from the output signal of the vertical amplifier. Retrace starts during the positive-going excursion of the input signal.

“Int—”—Selects the synchronizing voltage from the output signal of the vertical amplifier. Retrace starts during the negative-going excursion of the input signal.

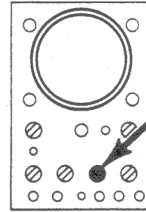
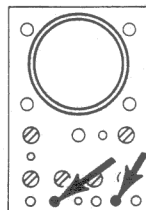
“H AMPL” Function

“Line”—Feeds an ac signal from the power supply to the horizontal amplifier to provide a sinusoidal horizontal sweep at power-line frequency.

“10X”—Attenuates the signal from the H INPUT terminal by a 10:1 ratio.

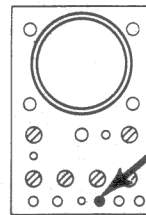
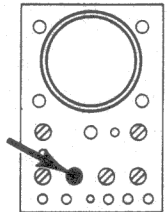
“1”—Feeds the unattenuated external voltage applied at the H INPUT terminal to the horizontal amplifier.

GND—Both GND terminals are connected directly to case and chassis.



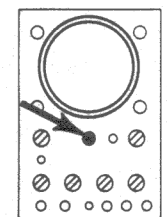
SWEEP—Selects the frequency range of the sweep oscillator. Used in conjunction with SWEEP VERNIER control. Positions “H” and “V” give sweep frequencies for viewing horizontal- and vertical-deflection waveshapes, sync-separator waveshapes and composite television signals.

SWEEP VERNIER—Provides continuous control of the oscillator sweep frequency over the range selected by the “SWEEP” switch. Also provides overlap of the SWEEP switch positions.

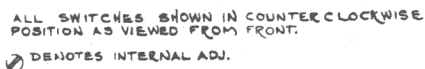


SYNC—External sync may be connected to this terminal. The SYNC H AMPL switch should be set to “EXT”. Note: the voltage applied to this terminal should not exceed approximately 15 volts peak-to-peak.

PHASE—Controls the phase of the synchronizing voltage when the SYNC H AMPL switch is set to “Line” (SYNC) position and controls the phase of the sinusoidal sweep voltage when the switch is set to the “Line” (H AMPL) position.



For information on the setting of the Astigmatism, Horizontal Balance, Vertical Balance, and Cal Coincidence Adjustments, which are accessible through holes in the case, see page 19 of the Maintenance Section.



Schematic Diagram of WO-78A

